Essays on nominal rigidities

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Essays on Nominal Rigidities: Identification, Macrodynamic Consequences and Policy Implications

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Chapter 1

Introduction

Most economists agree that, in the long run, changes in nominal variables such as the money supply or the nominal interest rate do not affect real economic activity. In this sense, it is well established that changes in the money supply by the monetary authority only influence the long-term price level and not the quantity of goods and services produced. In this context, money can be considered as a veil, and therefore, as established by the classical dichotomy, nominal and real variables can, in principle, be studied separately since the behavior of the former can be understood independently of the behavior of the latter.

This dichotomy does not apply in the short term. Empirical research dating back to at least the middle of the last century, of which Friedman and Schwartz (1963) is perhaps the most influential, shows evidence of a (at least statistical) relationship between nominal and real variables when their behavior is considered for periods of time relatively short, for example, a couple of months or quarters. Specifically, during these short periods of time, associated with economic cycles, several authors, using different econometric approaches, have found a positive correlation between the different monetary aggregates and also the nominal interest rates with the real output. The real short-term impact of these nominal variables, which to some extent are controlled by the monetary authority, opens the window to stabilization policies that motivate interventions aimed at counteracting the deviation of economic activity from its long term. For these stabilizing interventions to be successful, however, a deep understanding of the mechanism that generates the short-term link between nominal and real variables is required.

From the theoretical point of view, recent macroeconomic models rationalize the real effect of nominal variables by considering nominal and real frictions in the economy. New-Keynesian models, which have proved capable of reproducing stylized facts observed in actual economies, depart from the neoclassical assumptions of total flexibility in the goods and labor markets and of unimpeded adjustments of prices and wages. Instead, these models assume that firms and workers have differentiated goods and labor and, therefore, interact in a market characterized by monopolistic competition that allows them to establish their prices and wages.

Firms and households, however, can not set their prices or wages without restrictions. In this way, in addition to the real rigidity represented by the characteristic of the markets, and as empirical evidence suggests, New-Keynesian models assume that prices and wages cannot be freely set in each period, but instead are rigid in the sense that they remain constant for a certain period. With rigid prices, the monetary authority can influence real activity by changing nominal variables. The combination of real and nominal rigidities allows, for example, that after a negative demand shock that brings output below its long-term level, the monetary authority can respond by reducing the nominal interest rate. This change in its policy instrument, when (at least some) prices remain fixed, translates into a change in the real interest rate which, in turn, affects the real side of the economy, helping output to return to its long-term level.

The presence of rigidities in nominal wages has additional relevance in itself for at least three reasons. (i) The lack of flexibility of nominal wages, given its effect on real wages, hinders the ability of the labor market to adjust quickly to changes in economic conditions, thus generating non-optimal allocations of resources that may affect welfare. (ii) Several authors have found that including wage rigidities in New-Keynesian models improves the fit to the data and also contributes to the generation of impulse-responses that are more realistic. For example, Woodford (2003) shows that, without rigidity in nominal wages, real wages show a too abrupt response after a tightening of the monetary policy, even in the presence of price rigidity. In addition, Christiano, Eichenbaum and Evans (2005) found that, in terms of data fitting, incorporating nominal wage rigidity is more important than considering price rigidity. (iii) The presence of nominal wage rigidity has non-trivial implications for optimal monetary policy. As we know, in a scenario with only price rigidity, the optimal monetary policy corresponds to the objective of total stabilization of price inflation. In a scenario of rigidity of nominal wages, in addition to rigidity of prices, Erceg, Henderson and Levin (2000) showed that this is no longer the case. The optimal monetary policy, in this case, should focus on the stabilization of inflation of both prices and wages since fluctuations in both prices and wages have detrimental effects on welfare.

This dissertation aims to shed light on the identification, measurement, macrodynamic consequences and policy implications of nominal wage rigidity. The first two chapter of this dissertation deals with the modeling and impact of nominal wage rigidity from a theoretical/quantitative point of view.

In Chapter 2, entitled “Heterogeneity in Wage Setting Behavior in a New-Keynesian Model”, a joint work with Sylvester Eijffinger and Burak Uras, we estimate a New-Keynesian DSGE model with heterogeneity in price and wage setting behavior. In a recent study, Coibion and Gorodnichenko (2011) develop a DSGE model, in which firms follow four different types of price setting schemes: sticky prices, sticky information, rule-of-thumb, or flexible prices. We enrich Coibion and Gorodnichenko (2011) framework by incorporating heterogeneity in nominal wage setting behavior among households. We solve this DSGE model and estimate it using Bayesian techniques for the United States economy from 1955 to 2008. The estimation results show the relevance of heterogeneity in wage setting among households. More importantly, we identify qualitative and quantitative business cycle features allowed by the heterogeneity in wage rigidity, such as the persistence in price and wage inflation, which a standard New Keynesian model with only Calvo-type wage rigidity fails to achieve. We also show that modeling wage rigidity heterogeneity - as oppose to standard-Calvo-wages - amplifies the macroeconomic output fluctuations resulting from a technology shock while it mitigates the output fluctuations following a monetary tightening.

In Chapter 3, entitled “Stability and Welfare Effects of Increasing Wage Flexibility in the Presence of Financially Constrained Households” I analyze the stability and welfare effects of greater wage flexibility in an economy where a fraction of households do not have access to financial markets. I propose a medium-sized New Keynesian DSGE model and use it to investigate the effects of the interaction of these two frictions. The results show that once we consider limited asset market participation, greater wage flexibility increases the volatility of key macroeconomic variables. The volatility increases, even more, when the zero lower bound restricts the monetary policy. Regarding welfare, the analysis reveals that, in a context of limited asset market participation, greater wage flexibility is welfare improving only for implausible initial high degrees of wage rigidity; even in that case the gains are small. Except that extreme case, greater wage flexibility considerably reduces welfare when even a small fraction of households are financially constrained.

The study of wage rigidity would have only theoretical interest in the absence of evidence on the presence of this nominal rigidity in actual economies. The last chapter of this dissertation provides evidence of the rigidity of nominal wage and its determinants for the Netherlands.

Specifically, in Chapter 4, entitled "Rigid Wages & Contracts: Time- vs. State-Dependent Wages in the Netherlands", a joint work with Burak Uras and Nathanael Vellekoop, we study nominal wage rigidity in the Netherlands during the Great Recession. The data we use has three unique features: (1) high-frequency (monthly), (2) high-quality (administrative records), and (3) high coverage (the universe of workers and the universe of firms). We find substantial heterogeneity in the frequency of wage changes due to explicit terms of the labor contract. Contracts featuring flexible hours, overtime hours and contracts with a fixed period have a higher probability of a change in the contract wage. As a second finding, we report substantial heterogeneity in the wage rigidity between industries as well as differences within the year and between years. We estimate hazard models for the duration of a change in the contract wage, and confirm earlier findings in the literature that the hazard has two spikes, one at 12 months and one at 24 months. Moreover, we found that wage changes have a time and state dependency component. Once we split the sample based on contract characteristics, we find that the response of wage changes to the time and state component is heterogeneous across the different type of contracts. This heterogeneity is particularly evident in flexible-hours, tenured, full-time and part-time contracts.

Chapter 2

Heterogeneity in Wage Setting Behavior in a New-Keynesian Model

This chapter is based on a joint work with Sylvester Eijffinger and Burak Uras.

2.1 Introduction

It is well-documented that DSGE models require nominal rigidities (besides real frictions) to fit the data better and to replicate the dynamics observed in stylized facts. In particular, to generate the observed persistence in output and inflation, nominal rigidities are necessary (Woodford, 2003). Macroeconomists usually include nominal rigidities— which differentiate NK models from Real Business Cycle models— through an exogenous price-setting behavior of firms and wage setting behavior of households. For instance, the widely applied nominal rigidity scheme proposed by Calvo (1983) assumes that in every period only a fraction of randomly selected agents is allowed to set their prices or wages.[1] This approach, despite its convenience, is unappealing for two reasons. First, Calvo-type nominal rigidity leaves the mechanism unexplained by which a subset of firms are allowed to re-optimize their prices (or the wages for the case of households), while others are unable to do so.[2] Second, the underlying assumption of the Calvo scheme, in which agents that re-optimize their prices or wages, re-

[1] There is a profusion of literature on DSGE models using the Calvo scheme for prices and wages, with Smets and Wouters (2007) being one of the most influential.

[2] The same dynamic for price inflation could be obtained using a model with stronger microeconomics linkages given by quadratic cost of price adjustment, as in Rotemberg (1982).

optimize at the same time, is at odds with the behavior of firms and as workers observed in microdata.

Alternative approaches have been proposed in the DSGE literature to address the above-mentioned two limitations of the Calvo scheme. These alternatives include, for example, the use of state-dependent pricing and modeling of the nominal frictions using information rigidities instead of price rigidities; and, the utilization of more general specifications, which maintain the Calvo approach but incorporate some refinements and extensions to increase modeling flexibility. To this end, for instance, Coibion and Gorodnichenko (2011) suggest that modeling an economy by assuming a uniform price setting rule across firms has non-trivial consequences. In particular, consequences related to the ability of the model to fit the data, and, more importantly, for the determination of optimal monetary policy.

Our paper is related to this latter strand of literature and its contribution is twofold. First, we complement the studies dealing with the general equilibrium implications of heterogeneity in nominal rigidities. This is achieved by allowing heterogeneity in prices akin to Coibion and Gorodnichenko (2011) and extending their specification simultaneously to the wage setting heterogeneity among households. Specifically, we develop a New Keynesian DSGE model where firms and households are divided into four types and use their monopolistic power to set prices and wages according to four different rules. The rules we consider are: *Sticky prices a la Calvo*, *sticky information*, *full flexibility*, and *indexation*. We use Bayesian techniques to estimate the model for the United States economy for the period of 1955-2008, when the zero-lower bound was not binding. We also estimate alternative model specifications, where nominal-rigidity heterogeneity is considered only partially for prices as well as wages. The second contribution of our work is related to the use of the estimated models to investigate the macroeconomic impact of the heterogeneity in prices and wages over the business cycle —as in e.g., Aoki (2001), Carvalho (2006) and Stahlschmidt (2007).

Our key estimation results can be summarized as follows: We find that about 90% of firms follow Calvo-type price stickiness or informational stickiness when setting their prices - a quantitative result matching the findings of Coibion and Gorodnichenko (2011). As a novel finding of this paper, we show that at the household side only a total of 58% of the workers set their wages via Calvo-type wage stickiness or information stickiness. Therefore, the estimation results point out that wage-rigidity heterogeneity is more apparent than price heterogeneity when using a New-Keynesian model in matching the aggregate data. To delineate further on the dimension of heterogeneity, we find that over 20% of the households follow a flexible-wage rule, while the estimated population fraction of flexible price setters turns out to be only 5%. We also show that the model which incorporates heterogeneity in both wage and price setting behavior fits the data the best among a number of alternative models whose quantitative properties we evaluate. These findings contrast with the standard way of modeling wage determination where 100% of the households follow a Calvo sticky rule and more importantly, they cast doubts on modeling price and wage setting behavior symmetrically via standard Calvo setting. In this regard, our results show that although the assumption of all firms setting their prices according to a Calvo rule could be reasonable, extending this assumption to wage determination appears to be not appropriate when matching data.

We then conduct a business cycle analysis using the estimated model to distinguish the business cycle properties generated by wage-rigidity heterogeneity from standard New-Keynesian models. We identify interesting qualitative business cycle dynamics generated by the heterogeneity in wage rigidity, such as price and wage inflation persistence following monetary contractions that are prevalent characteristics of the business cycle data. Standard models with only Calvo-type wage rigidity fail to match such business cycle properties. Moreover, the impulse-responses reveal that allowing heterogeneity in wage rigidity amplifies the macroeconomic output fluctuations resulting from a technology shock whereas it mitigates the output fluctuations following a monetary tightening. As another key result we also show that models which do not incorporate any wage rigidity, generate implausible fluctuations of macroeconomic variables, such as for wage inflation.

Based on our findings, a key policy-relevant conclusion from the analysis is that the heterogeneity in wage staggeredness proves to be an important channel through which nominal rigidities could determine the level of monetary policy effectiveness. In this respect, our paper contributes to the growing literature aimed to understand the relevance of wage determination for the macroeconomy. Two important papers in this literature are Galí (2013) and Galí and Monacelli (2014). While Galí (2013) shows that in the context of a closed economy model, macroeconomic consequences of wage rigidities depend on the type of the monetary policy rule, Galí and Monacelli (2014) study the gains from wage flexibility for the case of an open economy and show that an increase in wage flexibility could reduce welfare - especially in economies under an exchange rate peg. We contribute to this important policy debate by emphasizing that it is not only the overall level of labor market flexibility but also its sectoral composition what matters for the macroeconomic policymaking.

The remainder of this paper is divided into five sections. Section 2.2 provides a summary of empirical findings regarding heterogeneity in price and wage setting behavior. Section 2.3 summarizes some findings about the relevance of wage rigidity for business cycles. In section 2.4, the model specification, its log-linear form, and equilibrium conditions are sketched. Sections 2.5 and 2.6 discuss the estimation methodology and present quantitative results, respectively, while in section 2.7, concluding remarks and suggestions for further research are presented.

2.2 Evidence of heterogeneity in price and wage setting

Extensive empirical literature shows that the price setting behavior is not homogeneous across firms and shows considerable variability. This variability depends on factors like the firm size, economies of scope or the existence of explicit or implicit contracts which impede even minor adjustments in prices.

Similarly, firms can be reluctant to change prices guided by the notion that consumers could wrongly relate a reduction in price with a reduction in the quality of the products, deterring in this way downward correction in prices. In addition, competition stances or failures in coordination among firms could make a firm not willing to change the price of its products for fear that competitors will not do the same. Finally, different pricing behavior could be a consequence of the traditionally studied implication of high costs (menu costs) for changing prices, which are different among firms (Hoeberichts and Stokman, 2006).[3,4]

One study that is particularly relevant for this paper is Coibion and Gorodnichenko (2011), where the authors solve and estimate a traditional NK DSGE model with flexible wages but heterogeneity in the price setting behavior among

[3] An interesting paper by Sheedy (2010) shows that allowing for heterogeneity in price determination generates an intrinsic persistence in aggregate inflation without the need to appeal to backward-looking pricing rules. The author achieves this result by moving away from the traditional assumption of random selection of firms that can adjust their prices and, instead, by assuming that the hazard function for changes in prices has a positive slope. We are not aware of a similar implementation for the case of the determination of wages, but this could suggest an additional channel through which the heterogeneity in the setting of wages is relevant for business cycles and monetary policy.

[4] A non-exhaustive list of papers dealing with heterogeneity in price setting behavior includes: Alvarez et al. (2006), Angeloni et al. (2006), Aoki (2001), Bils and Klenow (2004), Carlsson and Skans (2012), Carvalho (2006), Dhyne et al. (2006), Goldberg and Hellerstein (2009), Hoeberichts and Stokman (2006), Klenow and Kryvtsov (2008), Middleditch (2010), Midrigan (2011), Nakamura and Steinsson (2008) and Vermeulen et al. (2012).

firms. In particular, Coibion and Gorodnichenko (2011) consider that the economy is composed of four sectors whose only difference is the constraint (or lack of it) faced when setting prices. The four sectors considered are firms that use traditional sticky prices a la Calvo, firms that face sticky information, those that adjust their prices every period according to the last period's inflation, and firms that have flexible prices. Coibion and Gorodnichenko (2011) find that this kind of heterogeneity in prices improves the data fit performance of the model (casting doubts on specifications that only include one kind of rigidity or none at all). Also, the authors find that the non-consideration of the heterogeneity can hinder the task of the monetary authority and complicate the achievement of its stabilization objectives.

In contrast with a large body of literature dealing with heterogeneity in the rigidity of prices among firms, there are relatively fewer papers that empirically investigate heterogeneity in wage setting behavior. The scarcity of research on this topic was due to a great extent to the lack of appropriate data. Recently, high-frequency wage data become increasingly available - leading to a new strand of research to gain momentum. For example, in the case of France, using survey data from 1998 to 2005, Bihan, Montornès and Heckel (2012) find evidence of heterogeneity in the frequency of wage adjustments across sectors, occupations, and firm size. The authors also show a seasonal pattern in wage changes, which are more likely to occur in the first quarter. Besides the usual downward rigidity, the paper also finds a non-flat hazard function for wages having a peak in the fourth quarter.[5]

In a similar vein, using monthly administrative data from Luxemburg for the period of 2001-2006, Lünnemann and Wintr (2009) find high heterogeneity in wage flexibility for the nearly 11.000 firms considered in the sample. The authors show that the heterogeneity can be explained by firm size, whether the firm is private or public, and by industry. The authors also document a clear seasonal pattern for changes in wages, clustered in January and October.[6]

Sigurdsson and Sigurdardottir (2012) found similar results by conducting an empirical analysis using administrative monthly data for Iceland between 1998 and 2010. The authors find evidence of heterogeneity in wage flexibility across industries and occupations and strong support for this heterogeneity based on

[5] Bihan, Montornès and Heckel (2012) findings indicate that wages are more rigid in the service sector, especially for managers, and in firms with 20-49 employees. The authors show that wages closer to the minimum wage are more likely to change in the third quarter.

[6] Lünnemann and Wintr (2009) find that wage changes are more frequent for civil servants and white-collar workers.

firm size.[7] Additionally, the authors also show evidence of a seasonal pattern in the changes in wages, with nominal wages tending to increase in January and June.

Complementing these findings, Druant et al. (2012) find evidence of heterogeneity in wage rigidity across sectors based on survey information from the Wage Dynamic Network initiative for 17 European countries. In particular, the authors illustrate that wages change more frequently in construction, for larger firms and where the share of white-collar workers is small while are least frequent in trade and market services. Besides, their findings also suggest that competitive pressures within the sector are not relevant for wage flexibility. Concerning the seasonal pattern of wage changes, the paper documents a clear cluster of firms that change their wages principally in January, followed by a smaller cluster changing their prices in July.[8] Finally, the authors uncover a strong synchronization between price and wage changes.

Research regarding heterogeneity in wages for the United States has been scarce. Nonetheless, Barattieri, Basu and Gottschalk (2014) documented heterogeneity in the flexibility of wage setting for the U.S. between 1996 and 2004. Using data for four-month periods (infra-annual frequency) based on the results of the Survey of Income and Program Participation (SIPP), the authors show that wages are stickier in the manufacturing sector and more flexible in agriculture, mining, and services. Similarly, wages are less flexible for workers in managerial occupations compared with workers in direct production. As in other studies, the authors uncover empirical evidence of a seasonal pattern in the frequency of wage adjustments - that the frequency of wage changes is slightly higher in the second half of the year, and that the hazard function of a nominal wage is not constant, having a peak at 12 months. This behavior of the hazard function contradicts the Calvo framework.

Studies that include wage heterogeneity in macroeconomic models complement the evidence mentioned above. Particularly with respect to the seasonal pattern, Olivei and Tenreyro (2007) use a VAR model and find that in quarters where wages are more flexible (3rd and 4th), the responses of GDP and GDP defla-

[7] Regarding industries, Sigurdsson and Sigurdardottir (2012) findings reveal that wages are more flexible in transport and trade - and relatively more rigid in financial services. Regarding occupations, the analysis points out to lower rigidity in sales and support positions and higher rigidity for the managerial level. With regard to firm size, bigger firms tend to change their wages more frequently than smaller firms.

[8] Druant et al. (2012) find that the share of white-collar workers is positively associated with wage stickiness. The authors also show that the sectors that more clearly show a seasonal pattern in their wage adjustments are market and financial services, while construction is the sector with the least clear pattern.

tor after a monetary shock are weaker than in quarters where wages are less flexible. In contrast to traditional specifications within the Calvo framework, Olivei and Tenreyro (2007) assume that the probability of resetting wages is different in each quarter (calibrating this probability according to the empirical data for the United States). The authors show that this extended DSGE model generates impulse responses that quantitatively match those found in the actual data. In contrast to Olivei and Tenreyro (2007), where the seasonal heterogeneity is addressed, Dixon and Bihan (2012) investigate the effects of heterogeneity in the rigidity of wages across industries. Using data from France, the authors calibrate two independent variations for nominal rigidities: a so-called Generalized Taylor Economy (GTE), where firms have wage spells of different durations, and a Generalized Calvo Economy (GCE), where firms have different probabilities of resetting their wage (price). As the authors highlight, these two mechanisms "*allow the distribution of durations implied by the pricing model to be exactly the same as the distribution found in the actual micro-data.*" Dixon and Bihan (2012) find that after including these general specifications, the model can replicate the persistence of inflation and output observed in data. The authors also show that the GTE specification can generate a hump-shaped response of inflation and output that is not present in the standard Calvo framework - but widely observed in Business Cycle data.

Pfajfar and de Ridder (2017) found that heterogeneity in the rigidity of nominal wages across U.S. states has important effects on the propagation of monetary and fiscal shocks. Using microdata from the Current Population Survey, the authors calculate state-level downward nominal wage rigidity between 1980 and 2007 finding that, in states with a high degree of wage rigidity, contractionary monetary policy and tax shocks increase unemployment and decrease economic activity to a larger extent compared to states with more flexible wages. Intriguingly, the authors found an asymmetry in the effect of wage rigidities on the impact of shocks. Specifically, Pfajfar and de Ridder (2017) found that the degree of wage rigidity only affects contractionary shocks while the expansionary ones have little effect on real variables.

2.3 Wage Rigidity and Business Cycles

Several studies highlight the importance of staggered wage adjustments - alongside nominal price rigidities - in explaining business cycle data.[9] For instance,

[9] An extended treatment can be found in Woodford (2003).

Christiano, Eichenbaum and Evans (1999) and Christiano, Eichenbaum and Evans (2005) document that real wages are acyclical - or at best slightly procyclical, implying that any New-Keynesian model with nominal price frictions is consistent with business cycle real wage data if it incorporates nominal wage rigidities. Similarly, Christiano, Eichenbaum and Evans (1999) criticize sticky-price flexible-wage models because they imply an implausibly sharp real-wage decline after a negative monetary shock. Furthermore, Christiano, Eichenbaum and Evans (2005), Altig et al. (2002) and Smets and Wouters (2007) find out that models that incorporate both wage and price stickiness do a better job fitting the impulse responses - observed in the data - following a monetary shock.

Regarding the persistence, Andersen (1998) and Huang and Liu (1999) have argued that sticky wages generate more persistent real effects after a monetary perturbation compared to models of sticky prices. Finally, the model with both wage and price stickiness can capture richer wage dynamics vis-à-vis a model with flexible wages.

These arguments rationalize the incorporation of nominal wage frictions in a New-Keynesian DSGE framework alongside incomplete nominal price adjustments. In this paper, we aim to model and estimate business cycle implications of the heterogeneity in simultaneous nominal adjustment frictions in wages and prices.

2.4 The model

Let us consider the following New-Keynesian Economy. There are three types of agents: households, firms, and a monetary authority. Firms and households interact in a framework of monopolistic competition in labor provision and in production. There is heterogeneity in the way firms set their prices and the households set their wages. Specifically, four different rules for setting prices and wages are considered among firms as well as among households. This contrasts with traditional specifications used, e.g., in Smets and Wouters (2007), where staggered price and wage setting behavior - a la Calvo (1983) - is homogeneous across all economic agents.

Following Coibion and Gorodnichenko (2011) we assume that firms are divided into four types. Firms following a standard Calvo (1983) scheme, which set their prices by taking into account the likelihood of not being able to re-optimize in the following period. Firms that follow a scheme of *sticky information* a la Mankiw and Reis (2002) and therefore set their prices in every period but do it using an outdated information set. Firms with *flexible prices*, which set prices optimally in every period; and finally, firms following a *rule-of-thumb* which set prices mimicking the aggregate price inflation of the previous period.

We deviate from Coibion and Gorodnichenko (2011) by assuming that the above-mentioned four types of rules are also present in the case of wage setting among a distribution of heterogeneous household/workers who offer differentiated labor services to firms. This specification, therefore, makes it possible to encompass the heterogeneity in price and wage setting behavior simultaneously - as observed in the empirical data, which we discussed in the previous section.

The key features of our model are presented below.[10]

2.4.1 Firms

There is a continuum of firms indexed by $i \in [0,1]$, producing differentiated products using the following decreasing returns to scale production function,

$$Y_t(i) = A_t N_t(i)^{1-\alpha}.$$

Firms share the same total productivity, which in log terms follows the AR(1) process $a_t = \rho_a a_{t-1} + \epsilon_t^a$. In this setup $(1-\alpha)$ represents the elasticity of production with respect to labor while

$$N_t(i) = \left(\int_0^1 N_t(i,j)^{\frac{\epsilon_w - 1}{\epsilon_w}} dj \right)^{\frac{\epsilon_w}{\epsilon_w - 1}}$$

corresponds to an index of labor input, with $N_t(i,j)$ being the demand of labor type j by firm i and ϵ_w measures the elasticity of substitution between labor types. The labor types, which will be defined below, belong to households differing in their wage setting rules - with sticky wages, sticky information in wages, flexible wages and full indexed wages. It should be noted that, in this model, each firm uses all types of labor. Standard first-order conditions to the end of the production factor yield the demand for a particular type of labor as

$$N_t(i,j) = N_t(i) \left(\frac{W_t(j)}{W_t} \right)^{-\epsilon_w}$$

[10]The solution and estimation of the model was done using Dynare (Adjemian et al., 2011). The code is available upon request.

where $W_t(j)$ is the wage paid to that labor type while the aggregate wage rate is defined as

$$W_t = \left(\int_0^1 W_t(j)^{1-\epsilon_w} dj\right)^{\frac{1}{1-\epsilon_w}}.$$

Firms use their monopolistic power to set product prices. In order to model the heterogeneity in the price setting behavior, we assume that there are four different "sectors" of the economy and that each sector sets the price of its product following a different rule. In particular, two sectors face rigidities: a fraction s_{sp}^p of firms follows a Calvo pricing mechanism (*sticky prices*), while a fraction s_{si}^p follows a *sticky information* approach. Additionally, a fraction s_{fl}^p of firms sets prices in a *flexible* way, while a share s_{rot}^p of firms adjusts prices following a *rule-of-thumb* approach. Within the latter group, firms set prices according to the price inflation observed in the previous period.

2.4.1.1 Sticky prices

In the sector with sticky prices, firms follow a Calvo pricing mechanism. This means that in each period the probability of changing prices is $(1-\theta_{cp})$ where θ_{cp} is the probability of being unable to do so. The objective of these firms is to maximize the present value of their profits (2.1), with respect to the optimal price P_t^{*sp},

$$\sum_{k=0}^{\infty} \theta_{cp}^k E_t \left[Q_{t,t+k} \left(P_t^{*sp} Y(i)_{t+k|t} - \Psi(i)_{t+k} \left(Y(i)_{t+k|t} \right) \right) \right], \tag{2.1}$$

where $Q_{t,t+k}$ is the stochastic discount factor (see the household problem below) and $\Psi(i)_{t+k}$ is the total nominal cost. Firms optimize subject to the demand for their product, which is given by

$$Y(i)_{t+k|t} = C_{t+k} \left(\frac{P_t^{*sp}}{P_{t+k}} \right)^{-\epsilon_p},$$

where ϵ_p measures the elasticity of substitution between products and C_t is aggregate consumption.[11] The solution to this problem yields the following optimal pricing rule

$$P_t^{*sp} = \frac{\epsilon_p}{\epsilon_p - 1} \frac{\sum_{k=0}^{\infty} \beta^k \theta_{cp}^k E_t \left[C_{t+k}^{1-\sigma} P_{t+k}^{\epsilon_p} \psi(i)_{t+k|t} \right]}{\sum_{k=0}^{\infty} \beta^k \theta_{cp}^k E_t \left[C_{t+k}^{1-\sigma} P_{t+k}^{\epsilon_p - 1} \right]},$$

[11] Market clearing in the goods market requires $Y_t = C_t$.

where $\psi_{t+k|t}$ is the nominal marginal cost. After log-linearization, the following equation is obtained (hereafter, small caps represent the log of the variables and variables without time index represent steady state values):

$$p_t^{*sp} = \mu_p + (1-\beta\theta_{cp})\sum_{k=0}^{\infty}\beta^k\theta_{cp}^k E_t\left[mc(i)_{t+k|t} + p_{t+k}\right], \tag{2.2}$$

where $mc(i)_{t+k|t}$ is the log of the real marginal cost for firm i, and $\mu_p = -mc = \frac{1}{\epsilon_p - 1}$. In Equation (2.2) the optimal price depends on the real marginal cost of a particular firm, which is different from the aggregate real marginal cost given that the production function exhibits decreasing return to scale. It is possible to re-write (2.2) as a function of the average real marginal cost of the whole economy; therefore, yielding

$$p_t^{*sp} = (1-\beta\theta_{cp})\sum_{k=0}^{\infty}\beta^k\theta_{cp}^k E_t\left[\Theta\widehat{mc}_{k+t} + p_{k+t}\right] \tag{2.3}$$

with $\widehat{mc}_{k+t} = mc_{t+k} - mc$ and $\Theta = \frac{\alpha-1}{\alpha-\alpha\epsilon_p-1}$. The aggregate price in this sector is then expressed by

$$P_t^{sp} = \left(\theta_{cp}P_{t-1}^{sp}(i)^{1-\epsilon_p} + (1-\theta_{cp})\left(P_t^{*sp}\right)^{1-\epsilon_p}\right)^{\frac{1}{1-\epsilon_p}}, \tag{2.4}$$

where it is clear that firms that do not optimize in a given period leave their prices unchanged. Equation (2.4) can be used to calculate the log-linear version of price inflation in this sector as

$$\pi_t^{p,sp} = (1-\theta_{cp})\left(p_t^{*sp} - p_{t-1}^{sp}\right).$$

Then, using the optimal price found in (2.3), we get

$$\pi_t^{p,sp} = \beta E_t[\pi_{t+1}] + \frac{(\theta_{cp}-1)}{\theta_{cp}}\Theta(\beta\theta_{cp}-1)\widehat{mc}_t,$$

or in terms of the output gap $\tilde{y}_t = y_t - y_t^n$, where the superscript n denotes variables in their natural level without nominal rigidities, and the real wage gap ($\tilde{\omega}_t = \omega_t - \omega_t^n$):

$$\pi_t^{p,sp} = \beta E_t\left[\pi_{t+1}^p\right] - \frac{\left(\theta_{cp}-1\right)}{\theta_{cp}}\frac{(\alpha-1)\left(\beta\theta_{cp}-1\right)\tilde{\omega}_t}{\left(1-\alpha+\alpha\epsilon_p\right)} + \frac{\left(\theta_{cp}-1\right)}{\theta_{cp}}\frac{\alpha\left(\beta\theta_{cp}-1\right)\tilde{y}_t}{\left(1-\alpha+\alpha\epsilon_p\right)}. \tag{2.5}$$

Equation (2.5) corresponds to the standard New Keynesian Philips curve.

2.4.1.2 Sticky information

Following Mankiw and Reis (2002), in a given period only a fraction $(1-\theta_{ip})$ of the firms in the *sticky information* sector update their information, while the remaining θ_{ip} fraction does not, so the new information takes time to reach all firms. In this scenario, the aggregate price for the sector is

$$p_t^{si} = \sum_{j=0}^{\infty}(1-\theta_{ip})\theta_{ip}^{j} p_{t-j,t}^{si}, \tag{2.6}$$

where $p_{t-j,t}^{si}$ is the price set in period t using the outdated information from $t-j$. Thus, θ_{ip} is a measure of the degree of information stickiness in the sectors, i.e. if $\theta_{ip}=0$ no firms use old information.

Denoting $\left\{P_{t,t+k}^{si}\right\}_{k=0}^{\infty}$ as the future prices for a firm, which revises its price plan in period t, the problem of this firm is to choose a price plan that maximizes

$$\sum_{k=0}^{\infty}\theta_{ip}^{k} E_t\left\{Q_{t,t+k}\left(P_{t,t+k}^{si} Y(i)_{t+k} - \Psi(i)_{k+t}\left(Y(i)_{t+k}\right)\right)\right\}$$

subject to the demand for its product,

$$Y(i)_{t+k} = C_{t+k}\left(\frac{P_{t,t+k}^{si}}{P_{t+k}}\right)^{-\epsilon_p}.$$

The solution to this problem is of the form

$$P_{t,t+k}^{si} = \frac{\epsilon_p}{\epsilon_p-1} E_t\left[MC(i)_{t+k} + P_{t+k}\right],$$

for $k=0,1,2,\ldots$. Log-linerization yields

$$p_{t,t+k}^{si} = E_t\left[p_{t+k} - \frac{(\alpha-1)\widehat{mc}_{t+k}}{\alpha\epsilon_p-\alpha+1}\right],$$

which, together with the aggregate price for this sector (Equation (2.6)) provides us with the inflation rate in the sector with information stickiness:

$$\pi_t^{p,si} = \frac{1-\theta_{ip}}{\theta_{ip}}\sum_{j=1}^{J}\theta_{ip}^{j} E_{t-j}\left[\frac{\alpha\Delta\tilde{y}_t-(\alpha-1)\Delta\tilde{\omega}_t}{\alpha(\epsilon_p-1)+1} + \pi_t^{p}\right] + \frac{1-\theta_{ip}}{\theta_{ip}}\frac{\left(\alpha\tilde{y}_t-(\alpha-1)\tilde{\omega}_t\right)}{(\alpha(\epsilon_p-1)+1)}. \tag{2.7}$$

According to Equation (2.7), price inflation for firms with informational frictions is a weighted sum of expectations of the current price inflation for up to J

past periods, changes in the real wage gap, and changes in the output gap. In order to make this specification implementable, we set $J = 8$.[12]

2.4.1.3 Flexible price sector

In the flexible price sector, all firms optimize prices in every period. In this case, each firm has a one-period objective function and the optimal price in log terms is given by $p_t^* = mc(i)_t - mc + p_t$, while the sectoral inflation is

$$\pi_t^{p,fl} = p_t^{*fl} - p_{t-1}^{fl},$$

After some algebra and by using $mc(i)_t = mc_t + \frac{\alpha\epsilon_p\left(p_t^{*fl} - p_{k+t}^{fl}\right)}{\alpha-1}$ and $\widehat{mc}_t = mc_t - mc = \frac{\alpha\tilde{y}_t}{\alpha-1} - \tilde{\omega}_t$, we derive the sectoral inflation rate as:

$$\pi_t^{p,fl} = \pi_t^p - \frac{(\alpha-1)\tilde{\omega}_t}{\alpha\epsilon - \alpha + 1} + \frac{\alpha\tilde{y}_t}{\alpha\epsilon - \alpha + 1}. \tag{2.8}$$

2.4.1.4 Rule-of-thumb firms

Firms in the rule-of-thumb sector set their prices according to the prevailing price inflation rate in the previous period. Therefore, the inflation rate in this sector is simply given by:

$$\pi_t^{p,rot} = \pi_{t-1}^p.$$

2.4.1.5 Aggregate price inflation

Aggregate inflation is the weighted average of the inflation prevailing in each sector:

$$\pi_t^p = s_{sp}^p \pi_t^{p,sp} + s_{si}^p \pi_t^{p,si} + s_{fl}^p \pi_t^{p,fl} + s_{rot}^p \pi_t^{p,rot}. \tag{2.9}$$

It is worth to mention that in our framework sectoral inflation rates are dependent on the aggregate price inflation.[13]

[12] By construction, the number of past periods considered goes to infinity. The value chosen for J was determined for a technical reason related to the increasingly computational burden associated with higher values for J in the estimation process. As noted by Verona and Wolters (2013), in papers dealing with sticky information, the truncation point ranges from 3 to 252 periods.

[13] In order to guarantee that the estimated values for the share of each sector are between zero and one and add to 1, in the estimation step $\hat{s}_{sp}^p$, $\hat{s}_{si}^p$ and $\hat{s}_{fl}^p$ were considered. Therefore $s_{sp}^p = \hat{s}_{sp}^p$, $s_{si}^p = \hat{s}_{si}^p\left(1-\hat{s}_{sp}^p\right)$, $s_{fl}^p = \hat{s}_{fl}^p\left(\hat{s}_{sp}^p - 1\right)\left(\hat{s}_{si}^p - 1\right)$ and $s_{rot}^p = \left(1-\hat{s}_{sp}^p\right)\left(\hat{s}_{si}^p - 1\right)\left(\hat{s}_{fl}^p - 1\right)$. In spite of this, the reported values presented below corresponds to the shares in (2.9).

2.4.2 Households

There is a continuum of household/workers indexed by $j \in [0,1]$ who maximize their utility given by

$$E_0\left[\sum_{t=0}^{\infty}\beta^t U(C_t(j), N_t(j))\right].$$

The instantaneous utility of each household is represented by

$$U(C_t, N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\phi}}{1+\phi}, \tag{2.10}$$

where σ and ϕ denote the inverse elasticity of intertemporal substitution and the Frisch elasticity of labor supply, respectively. Households value a consumption index given by

$$C_t(j) = \left(\int_0^1 C_t(i,j)^{\frac{\epsilon_p-1}{\epsilon_p}}\,di\right)^{\frac{\epsilon_p}{\epsilon_p-1}}.$$

The consumption decision is a standard two-stage problem where in the first stage each household's demand for a variety j is given by $C_t(i,j) = C_t(j)\left(\frac{P_t(i)}{P_t}\right)^{-\epsilon_p}$ with $P_t = \left(\int_0^1 P_t(i)^{1-\epsilon_p}\,di\right)^{\frac{1}{1-\epsilon_p}}$. In the second stage the household maximizes its utility function with respect to the consumption index and labor subject to the budget constraint $P_t C_t(j) + Q_t B_t \leq B_{t-1} + W_t N_t + T_t$, where B_{t-1} is the number of bonds purchased in the previous period, $Q_t = \frac{1}{1+i_t}$ is the price of the bond and T_t is a lump-sum transfer representing taxes and dividends.[14]

The solution to the second stage problem yields the standard first-order conditions, which in log terms are expressed as

$$w_t - p_t = \sigma c_t + \phi n_t, \tag{2.11}$$

$$c_t = E_t[c_{t+1}] - \frac{1}{\sigma}\left(i_t - E_t\left[\pi_{t+1}^p\right] - \rho\right), \tag{2.12}$$

where $i_t = -\ln Q_t$ and $\rho = -\ln\beta$.

Given that households have monopolistic power over their differentiated labor they can set their wage rate. By analogy to the case of the price-setting behavior of firms, we assume heterogeneity in wage setting where different fractions of households set their wages following different types of rules. Specifically, a fraction s_{sp}^w of all households follows a Calvo mechanism (*sticky wages*) while another

[14]Bonds are riskless and have a one period maturity, i.e. each bond bought at period t pays one unit of money at $t+1$. In the model bonds are in zero net supply. Taxes are set to zero because we did not model the government.

fraction s^w_{si} follows a *sticky information* approach. Additionally, a fraction s^w_{fl} is allowed to set *flexible* wages while the remaining s^w_{rot} adjust wages according the rate of wage inflation observed in the previous period. We label this latter group as *rule-of-thumb* households.

2.4.2.1 Sticky wages

Following a Calvo scheme, in every period only a fraction $(1-\theta_{cw})$ of the households in the sticky wage sector can change their wages while the remaining θ_{cw} fraction keeps the same wage as in the previous period. That means the household maximizes

$$E_t\left[\sum_{k=0}^{\infty}\beta^k\theta_{cw}^k U(C_{t+k|t},N_{t+k|t})\right],$$

with respect to W_t^{*sw} subject to the constraints given by the demand for labor and the budget constraint,

$$N(j)_{t+k|t}=\left(\frac{W_t^{*sw}}{W_{t+k}}\right)^{-\epsilon_w}N_{t+k}$$

$$P_{t+k}C_{t+k|t}+E_{t+k}\left[Q_{t+k,t+k+1}D_{t+k+1|t}\right]\leq D_{t+k|t}+W_t^{*sw}N_{t+k|t}-T_{t+k}.$$

The solution to this problem is

$$W_t^{sw*}=\frac{\epsilon_w}{\epsilon_w-1}\frac{\sum_{k=0}^{\infty}E_t\left[u_c\beta^k N_{t+k}\theta_{cw}^k MRS_{t+k|t}W_{t+k}^{\epsilon_w}\right]}{\sum_{k=0}^{\infty}E_t\left[\frac{u_c\left(\beta^k N_{t+k}\theta_{cw}^k W_{t+k}^{\epsilon_w}\right)}{P_{t+k}}\right]},$$

where $MRS_t=-\frac{u_N}{u_c}$ is the marginal rate of substitution. In log terms, the equation for the optimal wage in the sticky-wage sector then becomes

$$w_t^{*sw}=\left(1-\beta\theta_{cw}\right)\left(w_t-\frac{\widehat{\mu}_{w,t}}{\phi\epsilon_w+1}\right)+\beta\theta_{cw}E_t w_{t+1}^{*sw},$$

with $\widehat{\mu}_{w,t}=\mu_{w,t}-\mu_w$ and $\mu_{w,t}=(w_t-p_t)-mrs_t$. We can express the wage inflation for this sector as in the following:

$$\pi_t^{w,sw}=\beta E_t\left[\pi_{t+1}^w\right]-\frac{(\theta_{cw}-1)}{\theta_{cw}}\frac{\widetilde{\omega}_t\left(\beta\theta_{cw}-1\right)}{\left(\phi\epsilon_w+1\right)}+\frac{(\theta_{cw}-1)}{\theta_{cw}}\frac{\widetilde{y}_t(\alpha\sigma-\sigma-\phi)\left(\beta\theta_{cw}-1\right)}{(\alpha-1)\left(\phi\epsilon_w+1\right)}.$$

2.4.2.2 Sticky information in wages

With sticky information in wages, the household chooses the following wage path

$$w_{t,t+k}^{si} = E_t\left[w_{t+k} - \frac{\widehat{\mu}_{w,t+k}}{\phi\epsilon_w + 1}\right],$$

yielding an aggregate wage rate for the sector as

$$w_t^{si} = \sum_{j=0}^{\infty}(1-\theta_{iw})\theta_{iw}^j w_{t-j,t}^{si},$$

which allows us to calculate the wage inflation for the sticky information sector as

$$\pi_t^{w,si} = \frac{1-\theta_{iw}}{\theta_{iw}}\sum_{j=1}^{J}E_{t-j}\theta_w^j\left[\pi_t^w + \frac{\Delta\widetilde{y}_t((\alpha-1)\sigma-\phi)-(\alpha-1)\Delta\widetilde{\omega}_t}{(\alpha-1)\left(\phi\epsilon_w+1\right)}\right] + \frac{(1-\theta_{iw})}{\theta_{iw}}\frac{\left(\widetilde{y}_t((\alpha-1)\sigma-\phi)-(\alpha-1)\widetilde{\omega}_t\right)}{\left((\alpha-1)\left(\phi\epsilon_w+1\right)\right)}. \tag{2.13}$$

According to Equation (2.13), wage inflation for households with informational frictions is a weighted sum of expectations of the current wage inflation for up to J past periods, changes in the real wage gap and in the output gap. As in the case of sticky information in prices we set $J=8$.

2.4.2.3 Flexible wages sector

In order to calculate the optimal wage in the flexible wage sector, the easiest procedure is to solve an objective similar to the one with sticky wages but by acknowledging that the objective is now a one-period program. The solution to this program yields the following wage inflation for the flexible-wages sector:

$$\pi_t^{w,fl} = \pi_t^w + \frac{\widetilde{y}_t(\alpha\sigma-\sigma-\phi)}{(\alpha-1)\left(\phi\epsilon_w+1\right)} - \frac{\widetilde{\omega}_t}{\phi\epsilon_w+1}. \tag{2.14}$$

2.4.2.4 Rule-of-thumb wages

In the rule-of-thumb wages sector, households set their wages according to the wage inflation rate observed in the previous period. Therefore, the wage inflation in this sector is simply given by

$$\pi_t^{w,rot} = \pi_{t-1}^w.$$

2.4.2.5 Aggregate wage inflation

Analogously to the price case, the aggregate wage inflation is computed as the weighted average of the sectoral wage inflations:[15]

$$\pi_t^w = s_{sp}^w \pi_t^{w,sp} + s_{si}^w \pi_t^{w,si} + s_{fl}^w \pi_t^{w,fl} + s_{rot}^w \pi_t^{w,rot}.$$

2.4.3 Monetary authority

Following Galí (2008), we assume that the policy rule is such that the monetary authority takes into account and responds to the deviations of output from its natural level and also to the evolution of price and wage inflation. In this respect, the nominal interest rate is given by

$$i_t = \lambda i_{t-1} + (1-\lambda)\big(\rho + \phi_p \pi_t^p + \phi_w \pi_t^w + \phi_y \widetilde{y}_t\big) + \nu_t, \tag{2.15}$$

where the disturbance term is an AR(1) process with $\nu_t = \epsilon_t^{\nu}$. The parameter λ captures the degree of interest rate smoothing.[16]

2.4.4 Equilibrium conditions

The derivation of the IS curve completes the model. This relation is derived, in output gap terms, using the Euler equation of the household (2.12) together with the market clearing condition $y_t = c_t$. The IS equation then gets expressed as

$$\widetilde{y}_t = -\frac{1}{\sigma}\big(i_t - E_t\big[\pi_{t+1}^p\big] - r_t^n\big) + E_t\big[\widetilde{y}_{t+1}\big], \tag{2.16}$$

where the output gap - $\widetilde{y}_t = y_t - y_t^n$ - is measured with respect to the natural output and the production level prevailing in the absence of nominal rigidities is given by $y_t^n = \psi_{ya}^n a_t + \vartheta_y^n$, with $\psi_{ya}^n = \frac{1+\phi}{\sigma(1-\alpha)+\phi+\alpha}$ and $\vartheta_y^n = -\frac{(1-\alpha)(\mu_p - ln(1-\alpha))}{(1-\alpha)\sigma+\phi+\alpha}$.

Additionally, the natural interest rate is defined as $r_t^n = \rho + \sigma\psi_{ya}^n E_t \Delta a_{t+1}$, while the natural wage follows $w_t^n = \psi_{wa}^n a_t + \vartheta_w^n$, where $\psi_{wa}^n = \frac{1-\alpha\psi_{ya}^n}{1-\alpha}$ and $\vartheta_w^n = \frac{(\mu_p - ln(1-\alpha))(\alpha\sigma-\sigma-\phi)}{\phi-\alpha\sigma+\alpha+\sigma}$. Finally, wage and price inflations are linked according to $w_t = w_{t-1} + \pi_t^w - \pi_t^p$. The complete model consist of 18 endogenous variables ($\widehat{y}_t$, y_t^n, y_t, r_t^n, n_t, π_t^p, π_t^w, w_t, w_t^n, i_t, $\pi_t^{p,sp}$, $\pi_t^{p,si}$, $\pi_t^{p,fl}$, $\pi_t^{p,rot}$, $\pi_t^{w,sp}$, $\pi_t^{w,si}$,

[15] The remarks in footnote 13 also apply in this case.

[16] The inclusion of wage inflation in the Taylor Rule is based on the notion that it is convenient that the Central Bank reacts to all the nominal rigidities observed in the economy, in the case of the paper at hand, rigidities in prices and in wages (Galí, 2008). In this regard, Erceg, Henderson and Levin (2000) and Amato and Laubach (2003*a*) found that it is desirable for the monetary policy, in the framework of simple interest rate rules, to respond to both price inflation and wage inflation.

$\pi_t^{w,fl}$, $\pi_t^{w,rot}$), 26 parameters (σ, α, ρ, ϕ_p, ϕ_w, ϕ_y, ρ_a, ρ_ν, σ_a, σ_ν, β, θ_{cp}, θ_{ip}, ϵ_p, θ_{cw}, θ_{iw}, ϵ_w, ϕ, λ, s_{sp}^p, s_{si}^p, s_{fl}^p, s_{sp}^w, s_{si}^w, s_{fl}^w, μ_p) and two exogenous process (a_t and ν_t). A list of all the equations of the model is available in Appendix 2.8.

2.5 Empirical Analysis

In order to investigate the empirical implications of the heterogeneity in wage and price setting behavior we estimate the model using Bayesian techniques. We utilize the Bayesian estimation methodology because of the well-known advantages of this full information procedure over other estimation methods. On the one hand, Bayesian techniques allow performing the estimation using pre-sample information stemming from data or past research. The pre-sample information, which is included in the estimation procedure as priors for the distribution of the parameters, is difficult to accommodate in classical estimation methodologies like Maximum Likelihood or Generalized Method of Moments. The pre-sample information is highly valuable because it helps to improve the identification of the parameters (DeJong, Ingram and Whiteman, 2000). On the other hand, Bayesian methodology, being a full information procedure, appears more appealing than procedures based on limited information such as the Simulated Method of Moments (McFadden, 1989) or a calibration exercise. The advantage over the former is that because Simulated Method of Moments is based only on a limited number of moments, and the disadvantage of calibration is that it lacks a formal statistical foundation (Kim and Pagan, 1999).

At an arguably deeper level, the main advantage of the Bayesian approach is its direct quantification of uncertainty. In other words, the Bayesian approach helps to make transparent the fact that in essence, all models are false. The Bayesian approach, therefore, takes into account the uncertainty associated with the parameters of the model and with the possible misspecification of the model itself. This in turn, as discussed by Gelman et al. (2014), facilitates the fitting to data of complicated models with several parameters and multilayer probability specifications. In addition, but not less important, given that in the Bayesian approach the parameters to be estimated are random variables, the "confidence intervals" have an intuitive interpretation that contrasts with that provided in the frequentist paradigm.[17]

[17] A brief description of Bayesian Methods and their application in DSGE models can be found in Fernández-Villaverde (2010) and An and Schorfheide (2007). A textbook approach is available in Canova (2007) and DeJong and Dave (2011).

We estimate the benchmark model with heterogeneity in prices and wages (hereafter the HpHw model) based on the standard priors used in the literature (Table 2.1). Specifically, mean, standard error, and the distribution for the elasticity of production with respect to labor $(1-\alpha)$, the parameters governing the reaction of the monetary policy with respect to the output gap (ϕ_y), to price inflation (ϕ_p) and the degree of interest rate smoothing (λ) were set according to Smets and Wouters (2007). The standard error and the distribution for the inverse of the elasticity of intertemporal substitution (σ) are also based on Smets and Wouters (2007). The prior mean for this parameter, however, was set according to Galí (2008) who assumes log-utility for consumer's preferences. Regarding the standard deviation of technology and policy shocks as well as the standard deviation of the measurement errors in the output gap and in wage inflation we take the priors from Rabanal and Rubio-Ramírez (2001). The parameters measuring the degree of price and wage stickiness a la Calvo $(\theta_{cp}$ and $\theta_{cw})$ follow a Beta distribution with a mean that incorporates the finding in the literature that wages tend to be less flexible than prices. By symmetry, the priors for the parameters governing information rigidity in prices and wages $(\theta_{ip}$ and $\theta_{iw})$ were set alike the Calvo case. Similarly, the autoregressive parameter for the evolution of the technology process (ρ_a) has the first and second moments as in Smets and Wouters (2007). Finally, the population share of each sector - with respect to price and wage setting behavior - is assumed to be equal to 0.25 with standard deviations of 0.15.[18] We do not estimate some of the parameters because they present problems for the identification of our model. To this end, we set the Frish elasticity of the labor supply (ϕ) to 1 as in Coibion and Gorodnichenko (2011) and the discount factor to 0.99 as in Rabanal and Rubio-Ramírez (2001). Finally, the elasticity of substitution between goods and labor is set according to Smets and Wouters (2007).

Following the tradition in the literature, we allow for measurement error for output gap and wage inflation.[19] We have a total number of 4 shocks in the model. Hence, when estimating we use four observed variables: output gap, price inflation, wage inflation, and nominal interest rate. Our sample covers 1955:1 to 2008:4 in quarterly periodicity for the United States. We explicitly excluded the data after 2008, when the zero-lower bound was active, to avoid

[18] This choice is based on the lack of information on the share of each of the four ways of setting prices and wages. We choose an equal prior share for each price and wage setting behavior to allow the estimation of the shares to start from a level playing field.

[19] Sargent (1989) and Karagedikli et al. (2010) discuss the importance of measurement error in improving the fit of DSGE models. Coibion and Gorodnichenko (2011) include measurement errors to absorb short-term fluctuations that are not modeled by the structural shocks.

Table 2.1: Priors

Parameter	Distribution	Mean	Standard error
β	Fixed	0.99	–
σ	Gamma	1	0.375
ϕ	Fixed	1	–
α	Normal	0.3	0.05
ϵ_w	Fixed	10	–
ϵ_p	Fixed	10	–
θ_{cw}	Beta	0.75	0.1
θ_{cp}	Beta	0.6	0.1
θ_{iw}	Beta	0.75	0.1
θ_{ip}	Beta	0.6	0.1
ϕ_p	Normal	1.5	0.25
ϕ_w	Normal	0.5	0.05
ϕ_y	Normal	0.12	0.05
ρ_a	Beta	0.5	0.2
s_{sp}^p	Beta	0.25	0.15
s_{si}^p	Beta	0.25	0.15
s_{fl}^p	Beta	0.25	0.15
s_{sp}^w	Beta	0.25	0.15
s_{si}^w	Beta	0.25	0.15
s_{fl}^w	Beta	0.25	0.15
λ	Beta	0.75	0.1
σ_a	Inverse Gamma	0.005	∞
σ_v	Inverse Gamma	0.005	∞
σ_y^{me}	Inverse Gamma	0.002	∞
$\sigma_{\pi_w}^{me}$	Inverse Gamma	0.002	∞

Note: The parameters are: Discount factor (β), Frish elasticity (ϕ), inverse of the elasticity of intertemporal substitution (σ), elasticity of production with respect to labor ($1-\alpha$), elasticity of substitution for products (ϵ_p), elasticity of substitution for labor types (ϵ_w), rigidity in wages a la Calvo (θ_{cw}), rigidity in prices a la Calvo (θ_{cp}), information rigidity in wages (θ_{iw}), information rigidity in prices (θ_{ip}), reaction to price inflation (ϕ_p), reaction to wage inflation (ϕ_w), reaction to output gap (ϕ_y), persistence for technology process (ρ_a), nominal interest rate smoothing (λ), share of firms with sticky prices (s_{sp}^p), share of firms with sticky information in prices (s_{si}^p), share of firms with flexible prices (s_{fl}^p), share of firms with rule-of-thumb prices (s_{rot}^p), share of households with sticky wages (s_{sp}^w), share of households with sticky information in wages (s_{si}^w), share of households with flexible wages (s_{fl}^w), share of households with rule-of-thumb wages (s_{rot}^w), standard deviation for technology process (σ_a), standard deviation for monetary process (σ_v), standard deviation for measurement error in output gap (σ_y^{me}) and standard deviation for measurement error in wage inflation ($\sigma_{\pi_w}^{me}$).

potential bias in the estimated parameters.[20] Except for the interest rate, we transform all variables using the natural logarithm and detrend them using the method proposed by Hamilton (2017). Specifically, stationarity is obtained by calculating, for a generic variable y_t, $v_{t+h} = y_{t+h} - y_t$ with $h = 8$, given that we have quarterly periodicity.[21] All data observations are from the Federal Reserve Bank of St. Louis database.

In our Bayesian estimation we use one chain - composed of 250.000 draws, 50.000 of which are discarded during the burning period. To check the stability of the chain, Geweke (1999) procedure was implemented. As it can be seen in Appendix 2.8, all parameters exhibit substantial convergence. The acceptance rate is 24.4%, which is sufficiently close to what it is considered optimal (around one forth, Koop (2003)).[22] The (theoretical) identification of all structural components are checked using the local identification analysis described by Iskrev (2010).

2.6 Results

In this section we provide the estimation results for our reference mode, and for a variety of alternative models. We also show the impulse-responses that allow us to understand the macroeconomic relevance of the heterogeneity in wage-setting behavior.

2.6.1 Estimation Results

Table 2.2 presents the estimation results for the posterior distributions of the benchmark model with heterogeneity in price and wage setting. In general, our

[20]Hirose and Inoue (2015) found that in linearized DSGE models that do not consider the zero-lower bound, the estimated parameters could be biased depending on the probability of hitting the zero-lower bound and the duration of its spell. As a robustness check we also estimated the model using the sample 1995:1 to 2014:1 finding no significant changes in the estimated parameters nor in the response of the variables to the shocks.

[21]This detrending method avoids the introduction of spurious dynamic relations in the detrended variable (a well-known issue of other methods e.g. the Hodrick-Prescott filter) and therefore "consistently estimates well-defined population characteristics for a broad class of possible data-generating processes" Hamilton (2017). As proposed by Hamilton (2017), we also stationarized the variables using $y_t - \hat{\beta}_0 - \hat{\beta}_1 y_{t-8} - \hat{\beta}_2 y_{t-9} - \hat{\beta}_3 y_{t-10} - \hat{\beta}_4 y_{t-11}$, obtaining similar results. We opted for $v_{t+h} = y_{t+h} - y_t$ because it does not depend on future observations of y_t and thus it has the convenience of one-sided approaches.

[22]We also estimate models using two chains with 500,000 replications each and an acceptance rate of about 1/3. The results are similar to those presented in this section. In addition, the univariate and multivariate convergence diagnosis of Brooks and Gelman show convergence for the 80% interval, the second and the third moment of the distribution. The results are available upon request.

estimates are in line with what other studies have found. For most parameters, the mean and the standard deviation of the prior distribution differ greatly from the corresponding moments of the posterior distribution. This difference is particularly evident for the parameters that measure the share of the different pricing and wage behaviors. A result like this indicates that the data is informative in the estimation of the subsequent distributions.

Regarding the estimated values, the model exhibits a value for the elasticity of intertemporal substitution of 0.21, which is similar to the value found by Rabanal and Rubio-Ramírez (2001) and in between what was found by Andrés, López-Salido and Nelson (2005) and Rabanal and Rubio-Ramírez (2005). The elasticity of production with respect to labor $(1-\alpha)$ closely matches the values previously estimated in the literature for the United States. Although we used different priors when estimating the degrees of price and wage stickiness a la Calvo, the estimated values end up being very similar to each other. The average duration of contracts with Calvo is 4 and 3.9 quarters for wages and prices, respectively. These values are comparable to what is usually found in the literature, e.g., they are within the boundaries estimated by Christiano, Eichenbaum and Evans (2005). These average durations are also similar to the findings in Smets and Wouters (2007) for wages and the findings in Rabanal and Rubio-Ramírez (2001) for prices. With respect to information rigidity, the estimated values show that this is more pronounced for prices and less pronounced to wages compared to the traditional rigidity a la Calvo. In particular, wage and price contracts with informational frictions have average durations of 4.7 and 2.6 quarters, respectively.[23] With regard to the parameter capturing the persistence of the technology disturbance process, the estimated value is in line with the estimates argued by others in the literature. In particular, the technology process shows very high persistence, highly consistent with the findings of Rabanal and Rubio-Ramírez (2005) and Galí (2008).

The estimation results indicate that a majority of the firms (85%) set their prices according to the Calvo rule. This high population estimate for Calvo-pricer firms can be confirmed with the findings of several papers in the literature, such as Klenow and Kryvtsov (2008), Coibion and Gorodnichenko (2011) and Carlsson and Skans (2012). Regarding the Calvo-rule, the estimate to the end of households' wage setting behavior is somewhat different: while Calvo-wage setters are also the majority of households, their population ratio (28% of the households)

[23] In comparison, Coibion and Gorodnichenko (2011) found and average duration for price contracts with informational frictions ranging from 4 to 20 quarters.

Table 2.2: Estimated values for the HpHw model

Parameter	**Mean**	**Standard Deviation**	**LB**	**UB**
σ	4.760	0.450	4.133	5.449
α	0.386	0.050	0.303	0.467
θ_{cw}	0.747	0.100	0.590	0.910
θ_{cp}	0.743	0.048	0.664	0.821
θ_{iw}	0.786	0.098	0.636	0.941
θ_{ip}	0.617	0.091	0.466	0.766
ϕ_p	1.505	0.218	1.138	1.852
ϕ_w	0.477	0.051	0.392	0.559
ϕ_y	0.106	0.049	0.029	0.189
ρ_a	0.782	0.032	0.733	0.838
s^p_{sp}	0.846	0.052	–	–
s^p_{si}	0.054	0.032	–	–
s^p_{fl}	0.054	0.026	–	–
s^p_{rot}	0.047	0.020	–	–
s^w_{sp}	0.278	0.177	–	–
s^w_{si}	0.184	0.081	–	–
s^w_{fl}	0.275	0.090	–	–
s^w_{rot}	0.262	0.098	–	–
λ	0.830	0.017	0.802	0.858
σ_a	0.033	0.004	0.027	0.040
σ_ν	0.004	0.001	0.004	0.004
σ^{me}_y	0.035	0.002	0.032	0.038
$\sigma^{me}_{\pi_w}$	0.009	0.001	0.008	0.009

Note: The parameters are: inverse of the elasticity of intertemporal substitution (σ), elasticity of production with respect to labor ($1-\alpha$), rigidity in wages a la Calvo (θ_{cw}), rigidity in prices a la Calvo (θ_{cp}), information rigidity in wages (θ_{iw}), information rigidity in prices (θ_{ip}), reaction to price inflation (ϕ_p), reaction to wage inflation (ϕ_w), reaction to output gap (ϕ_y), persistence for technology process (ρ_a), nominal interest rate smoothing (λ), share of firms with sticky prices (s^p_{sp}), share of firms with sticky information in prices (s^p_{si}), share of firms with flexible prices (s^p_{fl}), share of firms with rule-of-thumb prices (s^p_{rot}), share of households with sticky wages (s^w_{sp}), share of households with sticky information in wages (s^w_{si}), share of households with flexible wages (s^w_{fl}), share of households with rule-of-thumb wages (s^w_{rot}), standard deviation for technology process (σ_a), standard deviation for monetary process (σ_ν), standard deviation for measurement error in output gap (σ^{me}_y) and standard deviation for measurement error in wage inflation ($\sigma^{me}_{\pi_w}$). The delta method is used to calculate the standard deviation of the parameters measuring the share of firms and households. LB and UB stand for the Lower Bound and the Upper Bound of the 90% HPD interval.

is much lower than that of the Calvo-pricer firms. Both in terms of prices and wages, the share of agents who use the sticky information is relatively small - where the fraction is smaller for price setters (5%) than wage setters (18%). Another interesting estimate that we document is that compared to prices, wages appear to be more flexible given that 27% of households set their wages using the flexible wage setting rule compared to a population-ratio of flexible price setter-firms of 5%. Finally, the share of the households with indexed wages (26%) is greater than the corresponding fraction for indexed price setters (5%). These findings allow us to argue that regarding modeling heterogeneity of nominal-rigidities, households' wage setting heterogeneity is much more prevalent than firms' price setting heterogeneity when estimating a New-Keynesian model with aggregate data. This means a uniform Calvo price-setting rule could be a good representation for firms, but more heterogeneity appears to be relevant to the end of households.

In order to investigate the macroeconomic implications of the heterogeneity in price and wage setting behavior, we estimate five alternative models in addition to the benchmark Heterogeneous-Prices-Heterogenous-Wages (HpHw) model. Specifically, we estimate two models of flexible wage setting - one where heterogeneity in price setting (a model labeled as HpFw) is assumed and another one with only Calvo type price setting (labeled as CpFw). Additionally, we estimate two other models where wages are set a la Calvo. In one case of this second group, all price setters follow a Calvo scheme as well (labeled as CpCw) and in another case we allow for heterogeneity in the price setting behavior (labeled as HpCw). Finally, we also estimate a model where prices are flexible while there is heterogeneity in the wage setting behavior (labeled as FpHw). As Table 2.3 illustrates, the restricted specifications can be derived from the general model by fixing some corresponding parameters.

Table 2.4 presents the parameter estimates for all six models, which also includes our benchmark with heterogeneity in wage and price setting (HpHw). In general, and despite the differences in specifications, the estimated parameter values are comparable across models. Examples of the parameters that are robust to different specifications are the degree of information stickiness for prices and the parameter measuring the reactions of the monetary policy to changes in the output gap. The stability of the estimates for the elasticity of intertemporal substitution across models with rigidity in prices is also noteworthy. The average duration of price contracts a la Calvo ranges from 1.8 to 3.5 quarters while for price information rigidities the interval goes from 2.2 to 2.8 quarters. In this

Table 2.3: Specification for the six models to estimate

	Setting behavior		Shares	
Model	**Prices**	**Wages**	**Firms**	**Household**
HpHw	Heterogeneity	Heterogeneity	All estimated	All estimated
HpFw	Heterogeneity	Flexible	All estimated	$s^w_{fl} = 1$
CpCw	À la Calvo	À la Calvo	$s^p_{sp} = 1$	$s^w_{sp} = 1$
CpFw	À la Calvo	Flexible	$s^p_{sp} = 1$	$s^w_{fl} = 1$
HpCw	Heterogeneity	À la Calvo	All estimated	$s^w_{sp} = 1$
FpHw	Flexible	Heterogeneity	$s^p_{fl} = 1$	All estimated

Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages. The relevant parameters for this table are: share of firms with sticky prices (s^p_{sp}), share of firms with sticky information in prices (s^p_{si}), share of firms with flexible prices (s^p_{fl}), share of firms with rule-of-thumb prices (s^p_{rot}), share of households with sticky wages (s^w_{sp}), share of households with sticky information in wages (s^w_{si}), share of households with flexible wages (s^w_{fl}) and share of households with rule-of-thumb wages (s^w_{rot}).

respect, we find that overall, Calvo price stickiness is higher in models that incorporate heterogeneity in prices, and the estimate of this kind of price stickiness becomes higher when the heterogeneity is extended to wages. Average Calvo wage contract duration, in turn, gets estimated values between 2.8 and 6.2 quarters and, as in the case of price duration, it becomes higher once we allow for heterogeneity in the manner in which wages are set. It is also worth noting that even though the priors in the three models that take into account Calvo stickiness in prices and wages (HpHw, CpCw and HpCw) come along with a greater stickiness in wages than in prices, the estimated posteriors for models CpCw and HpCw show the opposite result. This is in contrast with findings in the literature e.g. Smets and Wouters (2003), Christiano, Eichenbaum and Evans (2005) and Galí, Smets and Wouters (2012), but is in line with the degree of stickiness found, for example, by Rabanal and Rubio-Ramírez (2001), Rabanal and Rubio-Ramírez (2005), Rabanal (2007) and De Graeve (2008).

In Table 2.4 we can also observe that there is a large variance in the parameter estimates measuring the reaction of the monetary policy rule with respect to the changes in price inflation. To this end, it is clear that in models where wages and/or prices are assumed to be flexible, the reaction to price inflation is almost 50% greater than in models where some kind of rigidity is considered in wages.

One of the main advantages of models with nominal rigidity heterogeneity is that they offer the possibility to calculate the shares of each sector—shares (as we documented above) that are not directly observable in the data. In this respect,

Table 2.4: Estimated values for the six models

Parameter	HpHw	HpFw	CpCw	CpFw	HpCw	FpHw
σ	4.760	4.055	4.699	4.250	4.559	4.243
α	0.386	0.222	0.358	0.232	0.375	0.372
θ_{cw}	0.747	–	0.639	–	0.640	0.838
θ_{cp}	0.743	0.578	0.684	0.455	0.715	–
θ_{iw}	0.786	–	–	–	–	0.937
θ_{ip}	0.617	0.542	–	–	0.642	–
ϕ_p	1.505	2.049	1.388	2.073	1.453	2.069
ϕ_w	0.477	0.496	0.480	0.500	0.478	0.500
ϕ_y	0.106	0.131	0.081	0.130	0.084	0.119
ρ_a	0.782	0.776	0.856	0.787	0.848	0.994
s_{sp}^p	0.846	0.211	1*	1*	0.821	–
s_{si}^p	0.054	0.367	–	–	0.070	–
s_{fl}^p	0.054	0.288	–	–	0.064	1*
s_{rot}^p	0.047	0.135	–	–	0.045	–
s_{sp}^w	0.278	–	1*	–	1*	0.190
s_{si}^w	0.184	–	–	–	–	0.432
s_{fl}^w	0.275	1*	–	1*	–	0.052
s_{rot}^w	0.262	–	–	–	–	0.326
λ	0.830	0.489	0.836	0.504	0.832	0.799
σ_a	0.033	0.013	0.029	0.012	0.027	0.005
σ_ν	0.004	0.009	0.004	0.009	0.004	0.004
σ_y^{me}	0.035	0.033	0.036	0.033	0.036	0.038
$\sigma_{\pi_w}^{me}$	0.009	0.012	0.009	0.013	0.009	0.009
Log marginal density	2746.39	2665.70	2745.36	2657.94	2744.97	2670.93

Note: * these parameters were not estimated but fixed. Column two of this table replicates column two of Table 2.2. In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

The parameters are: inverse of the elasticity of intertemporal substitution (σ), elasticity of production with respect to labor ($1-\alpha$), rigidity in wages a la Calvo (θ_{cw}), rigidity in prices a la Calvo (θ_{cp}), information rigidity in wages (θ_{iw}), information rigidity in prices (θ_{ip}), reaction to price inflation (ϕ_p), reaction to wage inflation (ϕ_w), reaction to output gap (ϕ_y), persistence for technology process (ρ_a), nominal interest rate smoothing (λ), share of firms with sticky prices (s_{sp}^p), share of firms with sticky information in prices (s_{si}^p), share of firms with flexible prices (s_{fl}^p), share of firms with rule-of-thumb prices (s_{rot}^p), share of households with sticky wages (s_{sp}^w), share of households with sticky information in wages (s_{si}^w), share of households with flexible wages (s_{fl}^w), share of households with rule-of-thumb wages (s_{rot}^w), standard deviation for technology process (σ_a), standard deviation for monetary process (σ_ν), standard deviation for measurement error in output gap (σ_y^{me}) and standard deviation for measurement error in wage inflation ($\sigma_{\pi_w}^{me}$).

it is not easy to make an extensive comparison against the findings in the literature due to the scarce availability of papers considering heterogeneity —with the exception of Coibion and Gorodnichenko (2011). Coibion and Gorodnichenko (2011) estimate the population fractions of 62%, 21%, 8%, and 9% for Calvo stickiness, sticky information, flexible, and rule-of-thumb prices, respectively. As we delineated, in our benchmark (HpHw) model estimation we also find that the majority of the firms follow the Calvo price setting behavior while the share of the firms that face some kind of stickiness in prices (basically the sum of Calvo price setters and sticky information firms) is 90%. Both results are in line with the findings of Coibion and Gorodnichenko (2011), where to the end of the latter the cumulative sum of firms which face Calvo and sticky information in Coibion and Gorodnichenko (2011) is 83%. The estimated population shares in the two papers are also similar for the case of flexible prices (5% in our study vs. 8% in Coibion and Gorodnichenko (2011)).

Another result to highlight is the drastic effect of the inclusion of rigidity on the estimated shares in models with heterogeneity in prices. Specifically, comparing the model HpFw with models HpHw and HpCw (a model with flexible wages versus two models with some kind of rigidity in wages) we can observe that the inclusion of stickiness in wages, irrespective of the presence of heterogeneity in this stickiness, substantially increases the estimated share of firms that follow a sticky price rule. The fact that the data favors a higher share of sticky price firms once sticky wages are included suggests that these two types of nominal rigidities reinforce each other when matching the macroeconomic data —a result that confirms the findings in previous empirical studies such as Druant et al. (2009).

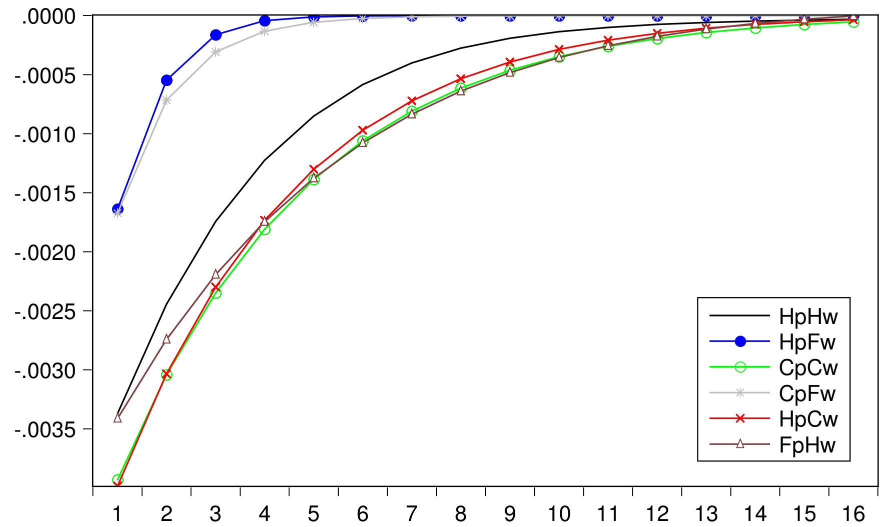
Finally, a basic model comparison regarding the ability of each model to fit the data confirms the usual result in the literature that models which consider only flexible prices or flexible wages are dominated by specifications where those are assumed to be rigid (last row of Table 2.4). In the same line, the comparison among models reveals that the posterior model probability favors the model which incorporates the simultaneous heterogeneity in price and wage setting behavior (Table 2.5). Most importantly, the benchmark model HpHw, with heterogeneity in price and wage setting behavior outperforms the traditional specification with prices and wages a la Calvo (CpCw) in fitting the data.

Table 2.5: Model comparison

Model	HpHw	HpFw	CpCw	CpFw	HpCw	FpHw
Priors	0.166	0.166	0.166	0.166	0.166	0.166
Log Marginal Density	2746.39	2665.70	2745.36	2657.94	2744.97	2670.93
Posterior Model Probability	0.627	0	0.222	0	0.151	0

Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

Figure 2.1: IRF for output gap after a monetary shock



Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

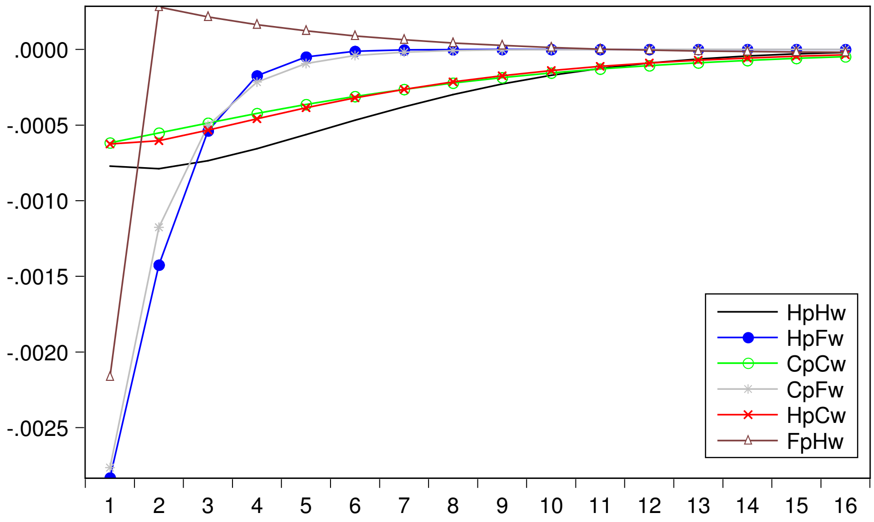
2.6.2 Implications of Wage Setting Heterogeneity for Monetary and Technology Shocks

2.6.2.1 Monetary Shocks

Figures 2.1-2.4 illustrate the responses of the four key model variables after a positive (tightening) monetary shock using the estimated monetary policy reaction function. For the output gap variable, the six models can be separated into two broad groups based on the incorporation of nominal wage rigidities. This is somewhat an expected result given that the estimated parameters across models within each group (nominal wage rigidity group vs. flexible wages group) are very similar, in particular the parameters measuring the population fractions of sectors with differing price setting behavior.

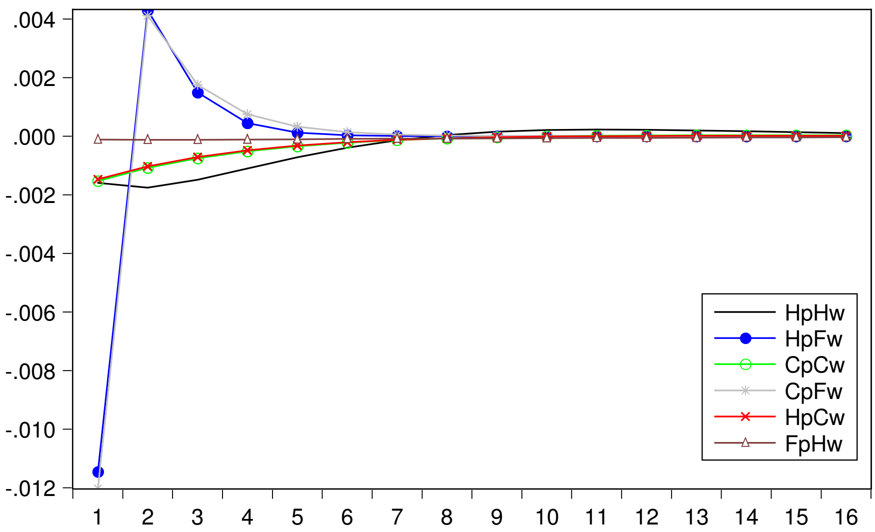
As a key contribution of our analysis, we find that the incorporation of heterogeneity in wage setting behavior yields impulse-responses that are different

Figure 2.2: IRF for price inflation after a monetary shock



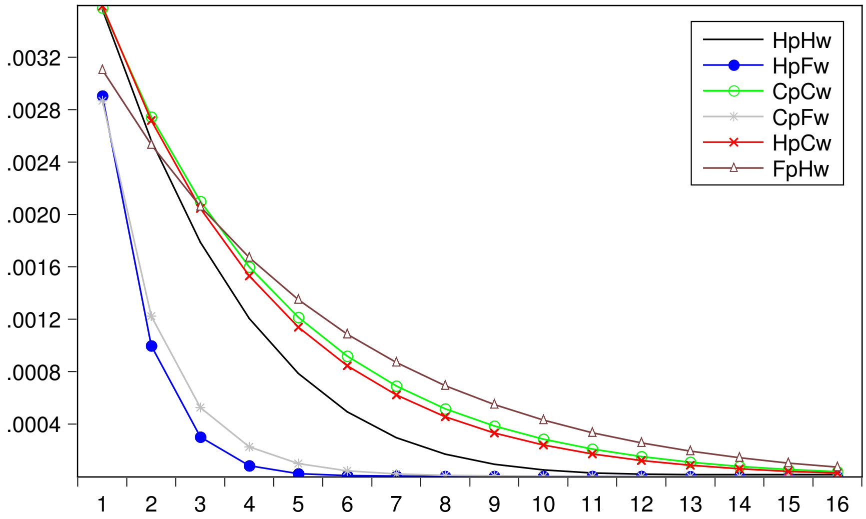
Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

Figure 2.3: IRF for wage inflation after a monetary shock



Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

Figure 2.4: IRF for nominal interest rate after a monetary shock



Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

from what one obtains using a more standard model where Calvo-type nominal wage setting is uniform across households. Particularly in models where price-setting heterogeneity is present, following a monetary contraction; the output gap contracts less and recovers more quickly in the model with heterogeneous wage setters compared to the model with uniform Calvo-type wage setting.[24]

We also obtain interesting qualitative effects of wage-setting heterogeneity on inflation. Specifically, with respect to the nominal price changes; when heterogeneity in wage setting is allowed, the pricing inflation exhibits some level of persistence following a monetary contraction. Such qualitative price inflation persistence cannot be observed in any of the other alternative model specifications. Similarly, following a monetary contraction, the model with wage setting heterogeneity generates wage inflation persistence, too. As a matter of fact, the model produces initially declining wage inflation and then a follow-up stagnation in wage inflation and then rising wage inflation. None of the alternative models are capable of generating this qualitative cyclical property either. This is an important qualitative result, because inflation persistence is a significant characteristic of the business cycle data as have been highlighted by Rotemberg and Woodford

[24]None of the estimated models are able to reproduce the hump shape in the response of output gap. This anomaly can be explained by taking into account that the models in the current paper are very stylized and do not take into account other rigidities, particularly consumption habits.

(1997), Christiano, Eichenbaum and Evans (1999), Altig et al. (2002), Rabanal and Rubio-Ramírez (2003) and Christiano, Eichenbaum and Evans (2005) (for prices) and by Edge, Laubach and Williams (2003) (for wages). Using VAR-based approaches these papers find a substantial amount of inertia and persistence in price and wage inflation following monetary contractions and show that to replicate these dynamics, DSGE models should exhibit strong internal propagation mechanisms. In this regard, Christiano, Eichenbaum and Evans (2005) conclude that this propagation mechanism could be achieved by incorporating additional frictions to the standard model, specifically the inclusion of habit formation, adjustment cost in investment and notably, variable capital utilization. We note that our benchmark model (HpHw) replicates the inertia and persistence of both price and wage inflation without relying on any of those propagation mechanisms.

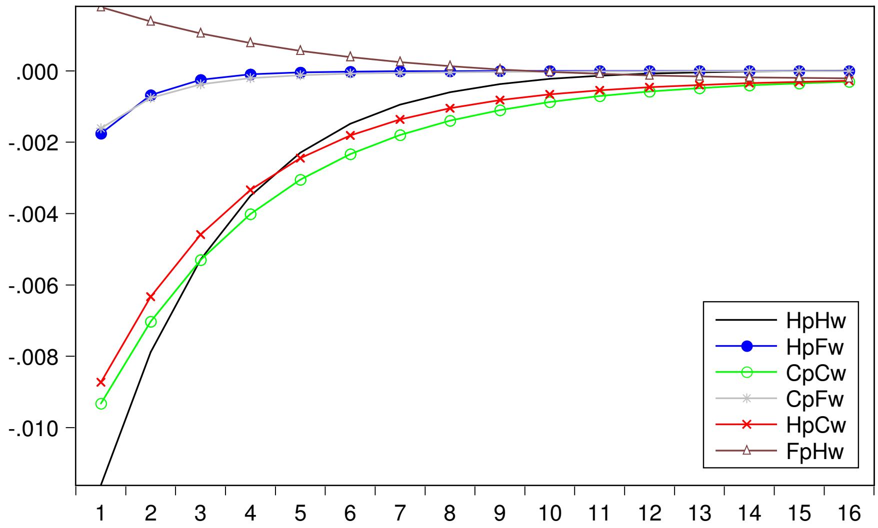
With respect to the nominal interest rate, the behavior of the set-up with heterogeneous wage rigidity shows qualitative similarities with the rest of the sticky-wages class of models. To this end, there is a striking quantitative difference though: The model with heterogeneous wage setting produces a nominal interest rate, which reacts to the monetary contraction significantly less compared to the models with standard Calvo-type nominal wage setting.

To the end of the overall nominal wage rigidity, Figure 2.3 illustrates the implausibly strong reaction of the wage inflation in models with flexible wages which is, as we delineated before, at odds with macro data. This strong reaction is followed by an implausibly large reaction into the opposite direction starting the second period. This effect is more persistent in the models where no heterogeneity in prices is considered because there is not a sector with flexible prices that can be adjusted. The muted behavior of wage inflation in models with sticky wages reduces the implication of the monetary shock for real wages. In this way it helps to counteract (through the marginal cost) the effect of such shocks on inflation resulting from the decline in the output gap. As a result, models with rigid wages exhibit more subtle reactions of price inflation (Figure 2.2). The lower the reaction of the price inflation, the higher and more persistent response of the nominal interest rate (Figure 2.4). This property brings as its consequence sharper contractions in output gap following monetary shocks (Figure 2.1).

2.6.2.2 Technology Shocks

The responses of the key macro variables following a technology shock are presented in Figures 2.5 to 2.8. As in the case of a monetary shock, the response to a

Figure 2.5: IRF for output gap after a technology shock



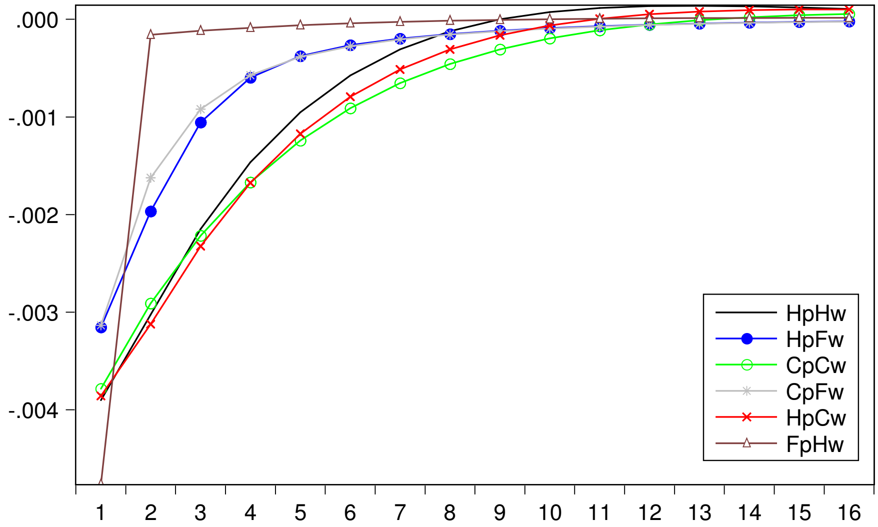
Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

technology shock is differentiated according to the presence of rigidity of nominal wages. It is worth noting that the responses for all variables are more persistent (compared to a monetary shock) given that for all models the estimated value for the persistence of the technology shock (ρ_a) is high. Qualitatively, the wage inflation persistence property of the heterogeneous wage setting model is observable following a technology shock as well. Price inflation behavior is comparable across the class models which incorporate nominal wage rigidities. Quantitatively, we obtain that the output gap and the nominal interest rate in the model with heterogeneous wage setting reacts more compared to the model with standard Calvo-type nominal wage setting.

Our results show that incorporating heterogeneity in wage rigidity–in addition to the heterogeneity in price setting–enriches the business cycle implications of a standard New-Keynesian model qualitative and quantitatively.

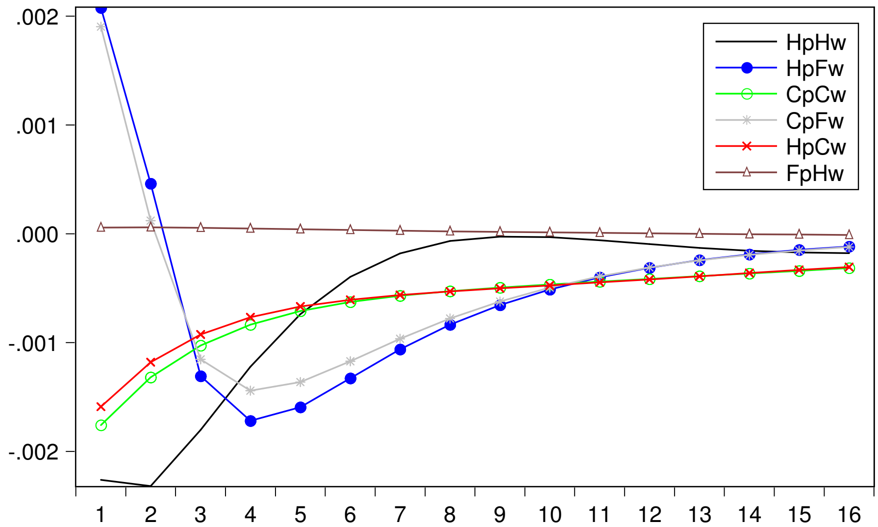
Figure 2.5 illustrates a strong decline in the output gap for the three models incorporating nominal rigidities in wages and a comparatively more pronounced decline once heterogeneity in wages is considered (HpHw). This reduction is explained by a strong rise in natural output, that is proportionally stronger in the model with heterogeneity in wage setting behavior. This is not a direct result of heterogeneity though, but rather a consequence of the estimated parameter val-

Figure 2.6: IRF for price inflation after a technology shock



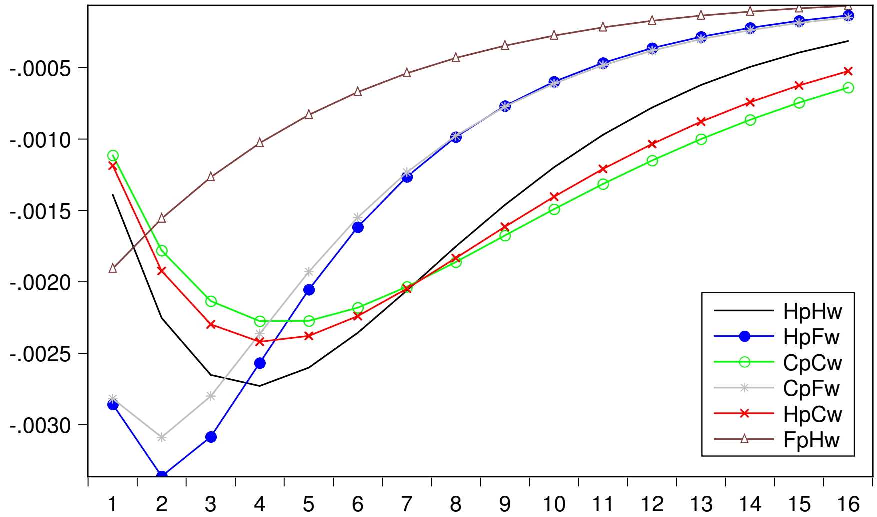
Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

Figure 2.7: IRF for wage inflation after a technology shock



Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

Figure 2.8: IRF for nominal interest rate after a technology shock



Note: In the acronyms of the models: H-Heterogeneity, C-Calvo, F-Flexible, p-Prices and w-Wages. Then, for example, HpFw corresponds to a model with Heterogeneity in Prices and Flexible Wages.

ues resulting from the model specification, particularly the lower estimated value of the inverse elasticity of substitution. Unsurprisingly, the output gap is more persistent in models where wages present some degree of rigidity. With respect to the price inflation (Figure 2.6), we can observe that all of the model specifications can capture the fall in price inflation following a technology shock. The response of price inflation (to a technology shock) closely correlates with the response of the output gap, where the response of price inflation to a technology shock is stronger whenever there is a large decline in output gap (except for the model with flexible prices). Figure 2.7 exhibits a larger variance in the response of wage inflation - with respect to a technology shock - in those models with flexible wages, which is a consequence of the pronounced positive response observed in the first periods - followed by even a more strong decline in wages in between periods three to seven. The dynamics of the nominal interest rate (Figure 2.8) is in line with the response of the output gap and the inflation in wages and prices. In particular, we can show that the reaction rule of the monetary policy in models with only flexible wages implies a strong reduction of the interest rate two periods following the technology shock in order to compensate for the large and more persistent reductions observed in the wage inflation.

2.6.3 Conclusions for monetary policy and wage flexibility

Our analysis builds upon the estimated DSGE model of Coibion and Gorodnichenko (2011) with strategic interaction among heterogeneous price setting by incorporating not only nominal wage rigidities but also heterogeneity in the wage-setting behavior. That makes our model more complete and more relevant for analyzing the interaction between price and wage rigidities. Some authors (e.g., Christoffel and Linzert (2010)) separate the production process in two steps with only wage rigidities in the intermediate sector and price rigidities in the final goods sector and thus not allowing for an interaction between price and wage rigidities in the model - unlike our set-up.

In our model there is a real interaction between price and wage rigidities - reinforcing the dynamics generated by each type of friction. More price rigidities lead to more wage rigidities and vice versa. Companies have less need to adjust their price setting if wages and their marginal costs change less frequently. Our Impulse Response Functions (IRF) in figures 2.1-2.4 show large differences between flexible and rigid wages as already concluded in the previous section, while the difference between Calvo wages and Heterogeneity in staggered wage adjustment (respectively Cw and Hw) seems to be less obvious than the difference with Flexible wages (Fw). This is from an intuitive point of view quite understandable.

On the basis of the IRF for the output gap after a monetary shock in Figure 2.1 and the IRF for price inflation after a monetary shock in Figure 2.2 we may conclude that given price rigidities it matters a lot for monetary policy whether there are wage rigidities or not. If wages are flexible, monetary policy is much more effective than if wages are sticky. In the case of wage flexibility the costs of monetary policy in terms of the output gap are also smaller than with wage rigidities. We also show that the effectiveness of monetary policy is higher with the standard-Calvo compared to the Heterogeneous wage setting model. Therefore, it turns out that heterogeneous wage setting behavior is decisive for both the effectiveness and costs of monetary policy. Two important papers recently studied the importance of wage flexibility for the conduct of monetary policy and macroeconomic performance: Galí (2013) studies a closed economy New Keynesian model and shows that macroeconomic consequences of wage flexibility depends on the type of the monetary policy rule choice of the Central Bank. For the context of an open economy, Galí and Monacelli (2014) illustrate that an increase in wage flexibility could reduce macroeconomic welfare in economies under an exchange rate peg. We contribute to this policy debate by emphasizing that it is not only the level of aggregate labor market flexibility but also the distribution of wage setting behavior across the economy what matters for the macroeconomic policymaking.

2.7 Conclusions

Nominal rigidities in prices and wages have proven to be two useful mechanisms that allow New Keynesian DSGE models to replicate several stylized facts observed in the data. For instance, the presence of nominal rigidities increases the persistence of some key variables after a shock and besides it allows for non-neutrality of monetary policy in the short run. However, the way this friction is usually incorporated in the DSGE models—staggering price and wage setting following Calvo (1983)—is somehow arbitrary, restrictive, and in contradiction to empirical findings regarding the timing of price and wage adjustments across economic sectors and occupations.

In order to bypass these shortcomings, several alternatives have been considered. These include models where the rigidity in prices and wages is not time dependent as in Calvo (1983) or Taylor (1999), but it is state dependent as in Caplin and Leahy (1991) or setups where nominal rigidities are the consequence of informational frictions (Mankiw and Reis, 2002). In addition, some authors have preferred a specification where the Calvo scheme is preserved but at the same time extended to include greater heterogeneity in price and wage setting by allowing, for example, for sectoral differences in firms and types of households.

This paper can be framed within this latter strand of research. Therefore, an otherwise standard New Keynesian DSGE model is considered, but it is assumed that four types of firms (sectors) and four types of households set their prices and wages according to four different rules. These rules are: sticky prices, sticky information, full flexibility, and indexation to previous price or wage inflation. The linearized model was estimated using Bayesian techniques for the United States from 1955 to 2008, and was then compared to more restricted specifications. Subsequently, the models were utilized to investigate the business cycle implications of wage-and-price setting heterogeneity.

Our estimation results show that most firms and households face rigidities in prices and wages either in a time-dependent manner or as a consequence of informational frictions. At the same time, the share of households with flexibility in wages is four times greater than the corresponding share of firms with flexible prices indicating that heterogeneity is an important feature characterize households' wage-setting behavior. The estimated model can produce impulse-responses are in line with the dynamics observed in actual data.

The impulse-responses also reveal that allowing heterogeneity in wage rigidity amplify the macroeconomic fluctuations resulting from a technology shock whereas they mitigate the macroeconomic fluctuations resulting from a monetary tightening. We also identify interesting qualitative business cycle dynamics generated by the heterogeneity in wage rigidity, such as price and wage inflation persistence, which standard models with only Calvo-type wage rigidity fail to achieve. Moreover, our results suggest that the standard approach of modeling prices and wages symmetrically is a very strong assumption whose effects are not trivial. Finally, we find that the model with heterogeneity in wage and price setting fits the data the best compared to the models where wages are allowed to be flexible and prices are set according to heterogeneous price-setting rules as in Coibion and Gorodnichenko (2011).

Incorporating heterogeneity in prices and wages in an otherwise standard DSGE model allows for compelling qualitative and quantitative results that deserve further attention. One natural path to follow is related to the implementation of the specification proposed in this paper, but in a medium-scale DSGE model in which other nominal, real and financial frictions are considered. Considering these additional frictions would help to isolate the implications of heterogeneity in prices and wages and facilitate the performance of data fitting across models. Another more substantial extension would be to make the heterogeneity in the price and wage setting behavior endogenous by, for example, linking it to financial constraints faced by firms and households. These extensions we leave to future research.

2.8 Appendix

2.8.1 Summary of the equations

$$
\begin{aligned}
\tilde{y}_t &= -\frac{1}{\sigma}\left(i_t - E_t\left[\pi^p_{t+1}\right] - r^n_t\right) + E_t\left[\tilde{y}_{t+1}\right] \\
\tilde{y}_t &= y_t - y^n_t \\
y^n_t &= \psi^n_{ya} a_t + \vartheta^n_y \\
y_t &= a_t + (1-\alpha) n_t \\
r^n_t &= \rho + \sigma \psi^n_{ya} E_t \Delta a_{t+1} \\
\pi^p_t &= s^p_{sp} \pi^{p,sp}_t + s^p_{si} \pi^{p,si}_t + s^p_{fl} \pi^{p,fl}_t + s^p_{rot} \pi^{p,rot}_t
\end{aligned}
$$

$$
\begin{aligned}
\pi_t^w &= s_{sp}^w \pi_t^{w,sw} + s_{si}^w \pi_t^{w,si} + s_{fl}^w \pi_t^{w,fl} + s_{rot}^w \pi_t^{w,rot} \\
w_t &= w_{t-1} + \pi_t^w - \pi_t^p \\
w_t^n &= \psi_{wa}^n a_t + \vartheta_w^n \\
i_t &= \lambda i_{t-1} + (1-\lambda)\left(\rho + \phi_p \pi_t^p + \phi_w \pi_t^w + \phi_y \widetilde{y}_t\right) + \nu_t \\
a_t &= \rho_a a_{t-1} + \epsilon_t^a \\
\nu_t &= \epsilon_t^v \\
\pi_t^{p,sp} &= \beta E_t\left[\pi_{t+1}^p\right] - \frac{\left(\theta_{cp}-1\right)}{\theta_{cp}} \frac{(\alpha-1)\left(\beta\theta_{cp}-1\right)\widetilde{\omega}_t}{\left(1-\alpha+\alpha\epsilon_p\right)} + \frac{\left(\theta_{cp}-1\right)}{\theta_{cp}} \frac{\alpha\left(\beta\theta_{cp}-1\right)\widetilde{y}_t}{\left(1-\alpha+\alpha\epsilon_p\right)} \\
\pi_t^{p,si} &= \frac{1-\theta_{ip}}{\theta_{ip}} \sum_{j=1}^{\infty} \theta_{ip}^j E_{t-j}\left[\frac{\alpha\Delta\widetilde{y}_t - (\alpha-1)\Delta\widetilde{\omega}_t}{\alpha(\epsilon_p-1)+1} + \pi_t^p\right] + \frac{1-\theta_{ip}}{\theta_{ip}} \frac{\left(\alpha\widetilde{y}_t - (\alpha-1)\widetilde{\omega}_t\right)}{(\alpha(\epsilon_p-1)+1)} \\
\pi_t^{p,fl} &= \pi_t^p - \frac{(\alpha-1)\widehat{\omega}_t}{\alpha\epsilon-\alpha+1} + \frac{\alpha\widetilde{y}_t}{\alpha\epsilon-\alpha+1} \\
\pi_t^{p,rot} &= \pi_{t-1}^p \\
\pi_t^{w,sw} &= \beta E_t\left[\pi_{t+1}^w\right] - \frac{\left(\theta_{cw}-1\right)}{\theta_{cw}} \frac{\widetilde{\omega}_t\left(\beta\theta_{cw}-1\right)}{\left(\phi\epsilon_w+1\right)} + \frac{\left(\theta_{cw}-1\right)}{\theta_{cw}} \frac{\widetilde{y}_t(\alpha\sigma-\sigma-\phi)\left(\beta\theta_{cw}-1\right)}{(\alpha-1)\left(\phi\epsilon_w+1\right)} \\
\pi_t^{w,si} &= \frac{1-\theta_{iw}}{\theta_{iw}} \sum_{j=1}^{\infty} E_{t-j}\theta_{iw}^j \left[\pi_t^w + \frac{\Delta\widetilde{y}_t((\alpha-1)\sigma-\phi) - (\alpha-1)\Delta\widetilde{\omega}_t}{(\alpha-1)\left(\phi\epsilon_w+1\right)}\right] \\
&\quad + \frac{(1-\theta_{iw})}{\theta_{iw}} \frac{\left(\widetilde{y}_t((\alpha-1)\sigma-\phi) - (\alpha-1)\widetilde{\omega}_t\right)}{\left((\alpha-1)\left(\phi\epsilon_w+1\right)\right)} \\
\pi_t^{w,fl} &= \pi_t^w + \frac{\widetilde{y}_t(\alpha\sigma-\sigma-\phi)}{(\alpha-1)\left(\phi\epsilon_w+1\right)} - \frac{\widehat{\omega}_t}{\phi\epsilon_w+1} \\
\pi_t^{w,rot} &= \pi_{t-1}^w.
\end{aligned}
$$

2.8.2 Convergence test for the simulated chain

In order to evaluate if the samples of the chain are truly representatives of the underlying stationary distribution of the Markov Chain, the procedure suggested by Geweke (1999) was implemented. This method compares the mean of two non overlapped portions of the chain, in particular, it compares draws between 5000 and 9000 to draws between 150000 and 250000. The results of a test for equality of means is presented in Table 2.6. It is important to note the differences in the p-value with different tapering values, this indicates the presence of auto-correlation in the draw, and therefore, as a more reliable p-value is this case is the one with 15% taper.

Table 2.6: Geweke convergence test

Parameter	p-value	p-value 4% taper	p-value 8% taper	p-value 15% taper
σ	0.997	0.999	0.999	0.999
α	0.000	0.730	0.724	0.703
θ_{cw}	0.940	0.993	0.993	0.993
θ_{cp}	0.000	0.464	0.459	0.411
θ_{iw}	0.000	0.421	0.380	0.288
θ_{ip}	0.000	0.404	0.382	0.372
ϕ_p	0.000	0.639	0.616	0.631
ϕ_w	0.134	0.856	0.855	0.862
ϕ_y	0.000	0.078	0.066	0.061
ρ_a	0.000	0.517	0.488	0.435
$\hat{s}_{sp}^{p}$	0.000	0.408	0.349	0.272
$\hat{s}_{si}^{p}$	0.000	0.146	0.143	0.157
$\hat{s}_{fl}^{p}$	0.002	0.725	0.727	0.705
$\hat{s}_{sp}^{w}$	0.000	0.575	0.549	0.503
$\hat{s}_{si}^{w}$	0.000	0.165	0.130	0.078
$\hat{s}_{fl}^{w}$	0.000	0.316	0.374	0.392
λ	0.000	0.158	0.120	0.088
σ_a	0.000	0.343	0.307	0.257
σ_v	0.165	0.884	0.868	0.851
σ_y^{me}	0.718	0.971	0.971	0.970
$\sigma_{\pi_w}^{me}$	0.000	0.141	0.132	0.157

Note: The parameters are: inverse of the elasticity of intertemporal substitution (σ), share of capital in production (α), rigidity in wages a la Calvo (θ_{cw}), rigidity in prices a la Calvo (θ_{cp}), information rigidity in wages (θ_{iw}), information rigidity in prices (θ_{ip}), reaction to price inflation (ϕ_p), reaction to wage inflation (ϕ_w), reaction to output gap (ϕ_y), persistence for technology process (ρ_a), nominal interest rate smoothing (λ), share of firms with sticky prices (s_{sp}^{p}), share of firms with sticky information in prices (s_{si}^{p}), share of firms with flexible prices (s_{fl}^{p}), share of firms with rule-of-thumb prices (s_{rot}^{p}), share of households with sticky wages (s_{sp}^{w}), share of households with sticky information in wages (s_{si}^{w}), share of households with flexible wages (s_{fl}^{w}), share of households with rule-of-thumb wages (s_{rot}^{w}), standard deviation for technology process (σ_a), standard deviation for monetary process (σ_v), standard deviation for measurement error in output gap (σ_y^{me}) and standard deviation for measurement error in wage inflation ($\sigma_{\pi_w}^{me}$).

2.8.3 Data

The data used in the estimation is from the United States for the period of 1955-2008 in quarterly periodicity. All data observations are from the Federal Reserve Bank of St. Louis database. In this paper four variables were used:

- Real Gross Domestic Product, Billions of Chained 2009 Dollars, Quarterly, Seasonally Adjusted Annual Rate (*GDPC1*).
- Gross Domestic Product: Implicit Price Deflator, Index 2009=100, Quarterly, Seasonally Adjusted (*GDPDEF*).
- Nonfarm Business - Hourly compensation - Index, base year = 100 - 2009 (*PRS85006103*).
- Effective Federal Funds Rate, Percent, Quarterly, Not Seasonally Adjusted (*FEDFUNDS*).

Chapter 3

Stability and Welfare Effects of Increasing Wage Flexibility in the Presence of Financially Constrained Households

3.1 Introduction

The urgency to find and understand instruments that could help moderate the damaging effects of economic crises on employment, consumption and output increased after the Great Recession. One instrument that policymakers usually bring to the table when considering those potential shock absorbers is a flexible labor market. The underlying assumption is that greater freedom to negotiate labor contracts at the level of firms, less stringent minimum wage laws and, importantly, greater flexibility in wages, are key features that help protect, at least to some extent, the economy from episodes of crisis.[1]

The neoclassical view of the relationship between wages and labor supports the notion that greater wage flexibility has a direct impact on employment. As Galí (2013) shows, in economies without nominal or real frictions -contrary to microeconomic evidence- competitive firms, taking wages as given, determine employment by demanding work to the point where the market wage is equal

[1] Take, for example, the reforms recommended by the European Central Bank to the countries under the financial assistance programmes at the end of 2012 (ECB (2012), page 62).

to the marginal productivity of labor. In this scenario, wages determine employment and, therefore, a decrease in wages (under the standard assumption of decreasing marginal productivity) generates an increase in labor demand.

However, in modern economies, where there are several nominal and real frictions and firms interact in monopolistically competitive markets, the link between wages and employment (and, therefore, consumption and output) is more subtle. In such New-Keynesian economies, the effects of wage changes on employment are indirect. In particular, how monetary policy and, therefore, aggregate demand respond to changes in wages, mediates these effects. As discussed by Galí (2013), the lack of a direct impact of wages on labor demand results from the assumptions underlying the Keynesian theory of employment. In (New) Keynesian economies, the demand for labor by firms depends on the level of production that firms want to achieve, which in turn depends on aggregate demand. Therefore, in contrast to the classical approach, where wages determine employment (and output), in New Keynesian models the causality between wages and employment is reversed.[2] An example can help us understand the relationship between wages and employment. Suppose, for instance, that we observe a decrease in wages. Lower wages translate into a reduction in inflation to which the monetary authority responds by adjusting the interest rate downward (expansionary policy). This reaction generates a positive impulse to aggregate demand that, only then, stimulates firms to increase their labor demand. Note that according to the causality in the example, it is the expansive policy stance that generates the increase in aggregate demand and subsequently in employment. It follows that if the ZLB restricts the interest rate, as I consider in this paper, we would expect to see a more subtle effect of wages on employment. However, as Fernández-Villaverde et al. (2015) and Basu and Bundick (2015) have shown, in response to various shocks, a restricted nominal interest rate would instead increase the volatility of the aggregate variables given that reaching the lower bound hinders the capacity of the interest rate to offset shock endogenously. This example helps also illustrate the ambiguous effect of wage flexibility on welfare in New-Keynesian. On the one hand, greater wage flexibility increases employment stability, improving welfare, but, on the other hand, increases inflation of prices and wages, which are costly in terms of welfare.

Considering households with financial constraints poses an additional complication for understanding the implications of greater wage flexibility in New-

[2] As mentioned by Galí (2013), "Under this perspective, a cut in nominal wages which is not accompanied by an expansion in aggregate demand will leave output, employment, and the real wage unchanged, and will have no impact on unemployment."

Keynesian economies. As we know, traditional households, with full access to financial markets, smooth their consumption intertemporally, thus limiting the effects of changes in their current income on their current consumption. Therefore, these households behave as indicated by the permanent income hypothesis.

This is not the case for households with financial restrictions. These hand-to-mouth households, due to their lack of financial inclusion (besides the lack of capital and ownership of the firms) have difficulties in smoothing their consumption.[3] Given that labor income represents the only income of hand-to-hand households, economic shocks affect their consumption path to a greater extent. This would suggest that for hand-to-mouth households, having a more stable labor income, resulting from a more stable wage due to a high degree of wage rigidity, would represent an improvement in their welfare, as it would help them reach a smoother consumption path. This generates a new channel through which wage flexibility affects macroeconomic stability and welfare.[4]

We can only achieve an adequate understanding of the effect of greater wage flexibility on macroeconomic stability and welfare when both the ambiguity generated by nominal rigidities and the impact of financial constraints on households are taken into account. In this paper, I consider an economy that includes these two channels. Specifically, I investigate the macroeconomic effects of increased wage flexibility by means of a medium-scale New Keynesian model à la Smets and Wouters (2007) that incorporates the now standard specifications on nominal rigidities in prices and wages, monopolistic competition, habit formation, investment with adjustment cost and variable capital utilization accumulation in a closed economy framework and where, additionally, a fraction of households do not have access to financial markets.

[3]Throughout this paper, we refer to financially constrained households as hand-to-mouth households. Literature sometimes refers to them as non-Ricardians or rule-of-thumb households.

[4]Several papers have found empirical support for the presence of financially constrained households. In a seminal paper Campbell and Mankiw (1989) found that for the United States in the pre-1990 period, the fraction of hand-to-mouth households were 50%. Recent papers have found that for the case of the United States, the weight of hand-to-mouth consumers is between 15% and 35% e.g. López-salido and Rabanal (2006), Bartolomeo, Rossi and Tancioni (2011) and Bilbiie and Straub (2013). The estimated weights for Europe are between 34% and 51%, e.g. Coenen and Straub (2005), Colciago et al. (2008) and Forni, Monteforte and Sessa (2009). The mentioned estimates are for pre-2008 financial crisis periods. It is reasonable to assume that during and after the crisis the fraction of households without access to financial markets increases. Marto (2014) found, for example, that for the Portuguese economy in the period 1995Q1-2012Q1 the fraction of hand-to-mouth households were 58%. However, new evidence suggests that this could not be the case. Demirguc-Kunt et al. (2018), for example, report an increase in the share of adults with access to a financial institution between 2014 and 2017: from 62% to 69% globally, and from 54% to 63% in developing countries.

In this paper, to model financial frictions, I move away from the representative agent assumption and consider two types of households: on the one hand, traditional Ricardian households with access to financial markets who can smooth their consumption intertemporally. On the other hand, hand-to-mouth households that do not have access to financial markets, do not own capital or own firms and whose consumption, consequently, depends solely on their current labor income. Using this calibrated model, I investigate the short-term effects on economic activity of greater wage flexibility by analyzing the response of key macroeconomic variables to nominal and real shocks. Also, this paper examines the welfare implications of the interaction between wage flexibility and households with financial constraints using a second-order approximation of the utility and policy functions. Given the above-mentioned relevance of the nominal interest rate, in the analysis I consider scenarios in which the zero lower bound is active and when it is not.

This analysis delivers two main findings. First, the responses of several key macroeconomic variables reveal that the traditional notion regarding the stability benefits of greater wage flexibility does not hold when even a small fraction of households do not have access to financial markets. The inability of these households to smooth their consumption intertemporally generates stronger and more persistent responses of, e.g., the real wage, output gap, and consumption. When the zero lower bound restricts the nominal interest rate, the volatility of these variables increases further, which highlights how important the monetary policy response is in a scenario of incomplete asset market participation.

Second, regarding welfare effects, I found that greater wage flexibility is, in general, detrimental to welfare when some households have financial constraints. There are small improvements in welfare associated with greater wage flexibility, but only when starting from a high (not plausible) initial rigidity, e.g., with salaries that only change every 20 quarters on average. Along the same lines, the analysis of the interaction between wage and price flexibility shows that greater wage flexibility only improves welfare when prices are also very flexible. Otherwise, when I assume that prices are relatively rigid and change on average each year, as empirical evidence suggests, greater wage flexibility is detrimental to welfare. I found, moreover, that with full participation in financial markets, the monetary authority can contribute to improving welfare by controlling the adverse effects of greater wage flexibility on inflation, while maintaining its beneficial effects on labor stability. However, when a fraction of households have financial constraints, this ability of the monetary authority disappears and greater wage flexibility decreases welfare regardless of how strong the response of the interest rate to inflation is.

This paper contributes to two strands of literature. On the one hand, to a vast literature that addresses the implications of considering households with financial constraints or with limited participation in the asset market. Papers like Mankiw (2000), Amato and Laubach (2003*b*), Galí, Lopez-Salido and Valles (2004), Galí, Lopez-Salido and Valles (2007), Bartolomeo and Rossi (2007), Bilbiie (2008), Leith and von Thadden (2008), Furlanetto (2011), Bi and Kumhof (2011), Colciago (2011), Furlanetto and Seneca (2012), Motta and Tirelli (2012), Natvik (2012), Ascari, Colciago and Rossi (2016) and Nisticò (2016), investigate the theoretical effects of the presence of financially constrained households for monetary and fiscal policy, and for the short-term response of macroeconomic variables to exogenous shocks.

On the other hand, this paper contributes to the literature that deals with the effects of wage flexibility on stability and welfare. In this sense, Galí (2013) found that the monetary policy rule followed by the central bank is decisive to conclude whether greater wage flexibility improves welfare. The author found that welfare can decrease with more flexible wages if the central bank follows a Taylor-type rule that responds weakly to price inflation. Along the same lines, Bils and Chang (2003) examine the impact of wage rigidity on welfare when employment has an effort and an hours dimension. The authors found that in the face of monetary shocks, the welfare cost of wage rigidity is small because the labor market clears through the effort margin, that is, after a shock, consumption (and aggregate demand) does not change significantly because agents adjust their level of effort.

In the framework of open-economy models, specifically an economy within a monetary union, Galí and Monacelli (2016) question the common opinion that an increase in wage flexibility is particularly desirable in a currency union. In this respect, the authors found that for a country within a currency union, the impact of labor cost on employment stability is lower than for a country with autonomous monetary policy and a price stability objective. The authors conclude that greater wage flexibility could be welfare reducing for an economy within a currency union, but it could increase welfare if a simultaneous increase in price flexibility accompanies the rise in wage flexibility.

Calmfors and Johansson (2006) reached similar results. The authors found that more flexible nominal wages increase employment stability but increase price variability, decreasing welfare. The authors conclude that more flexible wages within a monetary union are an imperfect substitute for an autonomous monetary policy because their effects only partially compensate for the increased variability of employment associated with union membership. Using a general equilibrium model of two countries, Spange (2008) shows that the flexibility of real wages increases the stability of consumption in both countries, increasing welfare. However, the impact of the consumption level on welfare depends on the parameters of the model. Therefore, the combined effect of consumption volatility and the consumption level on welfare is ambiguous. The author found that it could be the case that an equilibrium exists with flexible real wages in one country and rigid in the other, offering the possibility of welfare improving coordinated policy.

In a paper related to the present one, Ascari, Colciago and Rossi (2016) consider the interaction between financially restricted households and sticky wages finding that once they consider wage rigidity, limited asset market participation does not substantially affect welfare or the monetary policy design. The authors found that there is an effect only when they fix the fraction of households with financial restrictions on empirically implausible values. Compared with Ascari, Colciago and Rossi (2016) the present paper considers a medium-sized DSGE model that includes characteristics and shocks that have proven to be indispensable for the correct understanding of business cycles and to reproduce essential aspects of modern economies. Especially relevant for the analysis when some agents have financial restrictions, the present paper includes capital accumulation and utilization as control variables of households. Also, this paper focuses on the study of the response to economic perturbation when the zero lower bound is potentially binding.

More recently, in a model with workers (without access to financial markets) and capitalists (who own the production technology but do not work), Walsh (2017) found that welfare improves with greater wage flexibility under the optimal monetary policy. However, reaching the lower bound of the effective interest rate reverses this result. In relation to Walsh (2017), who considers a fixed level of capital, the present paper includes investment, which is costly to adjust, and the level of capital utilization as control variables of households. In addition, I carried out the welfare analysis using a second-order approximation around the inefficient steady state, which is arguably not only more accurate but also more realistic.

The remainder of this paper will proceed as follows. Section 3.2 describes the model economy. Section 3.3 analyses the response of dynamic responses of several macroeconomic variables to productivity, demand, labor and investment shocks while in Section 3.4 I discuss the welfare effects of greater wage flexibility in a framework of limited asset market participation. Section 3.5 concludes.

3.2 The model

Departing from the traditional way in which households are modeled on New-Keynesian models, households in this economy are heterogeneous regarding their access to financial markets. In particular, only a fraction of households have access to financial assets, which allows them to smooth their consumption intertemporally. The rest of households face liquidity constraints that force them to consume only their current labor income in each period.

The model considers all the characteristics, which have proved fundamental for fitting the data, of a full-fledged New Keynesian DSGE model in the spirit of Smets and Wouters (2003) and Smets and Wouters (2007) including habit in consumption, nominal and real frictions. Households and firms have monopolistic power over their labor and their products, respectively, allowing them to set wages and prices but only after receiving an exogenous random signal à la Calvo (1983).[5] Consequently, the model includes nominal rigidities since only a fraction of firms and households can set prices or wages in each period. Households owning capital choose its level of utilization and there is a cost associated with investment adjustments. The government is in charge of fiscal policy. Monetary policy follows a Taylor rule that takes into account inflation, the output gap, and its dynamic. The model considers a closed economy subject to eight shocks: preferences, productivity, labor supply, price and wage markup, government spending, investment and interest rate.

3.2.1 Households

There is a continuum of households indexed by $i \in [0,1]$ divided into two types. Both types share the same utility function and face the same shocks, but they are different in terms of their ability to smooth consumption. A fraction $(1-\vartheta)$ of households are of the standard Ricardian (or optimizer) type, common to New-Keynesian models. These households have access to financial instruments (government bonds), receive the profits of the firms, own the capital, which they rent to the firms after choosing its level of utilization and invest. In contrast, a fraction ϑ of households have financial restrictions. These hand-to-mouth households

[5] In the model the firms can hire and fire workers only restricted by the demand of their products. No employment protection regulations are considered.

do not have access to financial markets, do not possess capital, do not invest and do not own firms. Therefore, their only source of income comes from their labor (and perhaps some transfers).

3.2.1.1 Ricardian households

Each Ricardian household chooses consumption $\left(C_t^o\right)$, capital $\left(K_t^o\right)$, investment $\left(I_t^o\right)$, bonds $\left(B_t^o\right)$ and capital utilization (z_t) in order to maximize its utility function given by:

$$U_t^o(i)=\epsilon_t^{\mathrm{b}}\left(\frac{\left(C_t^o(i)-hC_t^o(i)\right)^{1-\sigma_c}}{(1-\sigma_c)}-\omega\epsilon_t^{\mathrm{L}}\frac{L_t^{\mathrm{o}}(i)^{1+\sigma_l}}{(1+\sigma_l)}\right)+\beta\mathrm{E}_t\left[U_{t+1}^o(i)\right],\ i\in(1-\vartheta,1]. \tag{3.1}$$

The parameter h measures habit formation, σ_c is the inverse of the elasticity of intertemporal substitution, ω parametrizes the disutility of labor, σ_l is the Frisch elasticity and β is the discount factor. The preference and labor supply shocks follow AR(1) processes given by $Ln\left(\epsilon_t^{\mathrm{b}}\right)=\rho_b Ln\left(\epsilon_{t-1}^{\mathrm{b}}\right)+\eta_t^{\mathrm{b}}$ and $Ln\left(\epsilon_t^{\mathrm{L}}\right)=\rho_L Ln\left(\epsilon_{t-1}^{\mathrm{L}}\right)+\eta_t^{\mathrm{L}}$, respectively. The maximization problem for the Ricardian household is restricted by its budget constraint and the evolution of capital:

$$\begin{aligned}
C_t^o(i)+I_t^o(i)+\frac{B_t^o(i)}{R_t}&=W_t^o(i)L_t^o(i)+r_t z_t(i)K_{t-1}^o(i)\\
&\quad-\frac{r_{ss}}{\psi}K_{t-1}^o(i)\left(e^{\psi(z_t(i)-1)}-1\right)+\frac{B_{t-1}^o(i)}{\pi_t}+Div_t^o(i)-T_t,\\
K_t^o(i)&=(1-\tau)K_{t-1}^o(i)+\epsilon_t^{\mathrm{I}}I_t^o(i)\left(1-\frac{1}{2}\varphi\left(\frac{I_t^o(i)}{I_{t-1}^o(i)}-1\right)^2\right).
\end{aligned}$$

R_t represents the gross nominal interest rate, $W_t^o(i)$ is the real wage, r_t is the return on capital, r_{ss} is the steady state return on capital, π_t is the aggregate price inflation, $Div_t^o(i)$ are the dividends and T_t are transfers from the government. There is an investment shock whose dynamics is given by $Ln\left(\epsilon_t^{\mathrm{I}}\right)=\rho_I Ln\left(\epsilon_{t-1}^{\mathrm{I}}\right)+\eta_t^{\mathrm{I}}$. The depreciation rate is given by τ while ψ and φ are scale parameters.

The first order condition are:

$$\begin{aligned}
0&=\beta\mathrm{E}_t\left[\frac{\lambda_{t+1}^{\mathrm{o}}}{\pi_{t+1}}\right]-\frac{\lambda_t^{\mathrm{o}}}{R_t},\\
\lambda_t^{\mathrm{o}}&=\epsilon_t^{\mathrm{b}}\left(C_t^{\mathrm{o}}-hC_{t-1}^{\mathrm{o}}\right)^{-\sigma^{\mathrm{c}}},\\
q_t&=\beta\left((1-\tau)\mathrm{E}_t\left[q_{t+1}\right]+\mathrm{E}_t\left[\lambda_{t+1}^{\mathrm{o}}\left(r_{t+1}z_{t+1}-r_{ss}\frac{\left(e^{\psi(z_{t+1}-1)}-1\right)}{\psi}\right)\right]\right),
\end{aligned}$$

$$
\begin{aligned}
\lambda_t^{\mathrm{o}} = q_t & \left(\epsilon_t^{\mathrm{I}} \left(1 - \frac{1}{2} \varphi \left(\frac{I_t^{\mathrm{o}}}{I_{t-1}^{\mathrm{o}}} - 1 \right)^2 \right) - \varphi \epsilon_t^{\mathrm{I}} \frac{I_t^{\mathrm{o}}}{I_{t-1}^{\mathrm{o}}} \left(\frac{I_t^{\mathrm{o}}}{I_{t-1}^{\mathrm{o}}} - 1 \right) \right) \\
& + \beta \varphi \frac{1}{I_t^{\mathrm{o}^2}} \mathrm{E}_t \left[\epsilon_{t+1}^{\mathrm{I}} q_{t+1} I_{t+1}^{\mathrm{o}^2} \left(\frac{I_{t+1}^{\mathrm{o}}}{I_t^{\mathrm{o}}} - 1 \right) \right], \\
r_t = r_{ss} & e^{\psi(z_t - 1)},
\end{aligned}
$$

where q_t is Tobin's q and λ_t^{o} is the marginal utility of consumption for Ricardians.

3.2.1.2 Hand-to-mouth households

Hand-to-mouth households have the same utility function as optimizers and choose their consumption level $\left(C_t^{\mathrm{nr}}\right)$ that maximizes it. Here, however, the budget constraint is simpler and only contains labor income and transfers, that is

$$
U_t^{\mathrm{nr}}(i) = \epsilon_t^{\mathrm{b}} \left(\frac{\left(C_t^{\mathrm{nr}}(i) - h C_t^{nr}(i)\right)^{1-\sigma_c}}{(1-\sigma_c)} - \omega \epsilon_t^{\mathrm{L}} \frac{L_t^{\mathrm{nr}}(i)^{1+\sigma_l}}{(1+\sigma_l)} \right) + \beta \mathrm{E}_t \left[U_{t+1}^{\mathrm{nr}}(i) \right], \ i \in [0, \vartheta), \tag{3.2}
$$

subject to $C_t^{\mathrm{nr}}(i) = W_t^{\mathrm{nr}}(i) L_t^{\mathrm{nr}}(i) - T_t$. The first order condition is given by

$$
\lambda_t^{\mathrm{nr}} = \epsilon_t^{\mathrm{b}} \left(C_t^{\mathrm{nr}} - h C_{t-1}^{\mathrm{nr}} \right)^{-\sigma^{\mathrm{c}}},
$$

where λ_t^{nr} is the marginal utility of consumption for hand-to-mouth households.

3.2.2 Labor supply and wage setting

As in Schmitt-Grohé and Uribe (2005) and Colciago (2011), I suppose that firms hire from a continuum of labor markets indexed by $s \in [0,1]$ each one represented by a different union. Each household i supplies all types of labor and, given the wage set by the union (W_t^s), will supply the amount of labor demanded by firms (L_t^s) according to

$$
L_t^s = L_t^d \left(\frac{W_t^s}{W_t} \right)^{-\frac{1+\lambda_w}{\lambda_w}}. \tag{3.3}
$$

The parameter λ_w is the markup in the labor market and L_t^d, W_t are the aggregate labor demand and aggregate wages, respectively (these will be explained later). The demand for labor type s is split uniformly across the households so that households supply an identical amount of labor services ($L_t^{\mathrm{o}}(i) = L_t^{\mathrm{nr}}(i) = L_t$). The total number of hours allocated to the different labor markets/unions must satisfy the resource constraint $L_t = \int_0^1 L_t^s ds$. Combining this constraint with (3.3) yields

$$L_t = L_t^d \int_0^1 \left(\frac{W_t^s}{W_t}\right)^{-\frac{1+\lambda_w}{\lambda_w}} ds.$$

It follows that the labor income for Ricardians and hand-to-mouth households is the same and is given by $W_t^o(i)L_t^o(i) = W_t^{\mathrm{nr}}(i)L_t^{\mathrm{nr}}(i) = L_t^d \int_0^1 W_t^s \left(\frac{W_t^s}{W_t}\right)^{-\frac{1+\lambda_w}{\lambda_w}} ds.$

Since households have differentiated labor, they enjoy monopolistic power and can set their wage, which they can change subject to receiving a random wage–change signal(Calvo, 1983). The probability of receiving this signal (and, therefore, the fraction of households that can change their wage) is given by $(1-\theta_w)$. The rest of the households θ_w can not establish their wages optimally but index them to price inflation according to:

$$W_t^s = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w} W_{t-1}^s,$$

where γ_w represents the degree of wage indexation.

The union problem is therefore to choose a wage that maximizes the discounted weighted average difference between the utility of consumption obtained from labor income and the disutility associated with the loss of leisure of both types of households taking into account the probability of changing wages and the demand for their labor (given by (3.3)) as follows

$$\begin{aligned}\max_{W_t^s} \quad E_t\Bigg[\sum_{\tau=0}^{\infty}(\beta\theta_w)^{\tau}\Bigg(\upsilon\Bigg(\lambda_{t+\tau}^{nr}(i)\Bigg(\prod_{s=1}^{\tau}\frac{\pi_{t+s-1}^{\gamma_w}}{\pi_{t+s}}\Bigg)W_t^s(i)L_{t+\tau}^{nr}(i)-\epsilon_t^{\mathrm{b}}\epsilon_t^{\mathrm{L}}\omega\frac{L_{t+\tau}^{nr}(i)^{1+\sigma_l}}{1+\sigma_l}\Bigg)\\ +(1-\upsilon)\Bigg(\lambda_{t+\tau}^{o}(i)\Bigg(\prod_{s=1}^{\tau}\frac{\pi_{t+s-1}^{\gamma_w}}{\pi_{t+s}}\Bigg)W_t^s(i)L_{t+\tau}^{o}(i)-\epsilon_t^{\mathrm{b}}\epsilon_t^{\mathrm{L}}\omega\frac{L_{t+\tau}^{o}(i)^{1+\sigma_l}}{1+\sigma_l}\Bigg)\Bigg)\Bigg].\end{aligned}$$

$\lambda_t^h(i)$, $h \in \{o, nr\}$ represents the marginal utility of consumption for Ricardians and hand-to-mouth households, respectively. The solution to this problem can be written recursively as

$$\begin{aligned}f_t^1 &= W_t^{*^{-1-\left(1+\frac{1}{\lambda_w}\right)\sigma_l}}\Bigg((1+\lambda_w)\omega L_t^{1+\sigma_l} W_t^{\frac{(1+\lambda_w)(1+\sigma_l)}{\lambda_w}}\epsilon_t^{\mathrm{b}}\epsilon_t^{\mathrm{L}}\\ &\quad + E_t\Bigg[\beta\theta_w f_{t+1}^1\left(\frac{\pi_t^{\gamma_w}}{\pi_{t+1}}\right)W_{t+1}^{*^{1+\left(1+\frac{1}{\lambda_w}\right)\sigma_l}}\Bigg]\Bigg),\\ f_t^2 &= E_t\left[\beta\theta_w f_{t+1}^2\left(\frac{\pi_t^{\gamma_w}}{\pi_{t+1}}\right)^{-\frac{1}{\lambda_w}}\right]+\upsilon L_t W_t^{\frac{1+\lambda_w}{\lambda_w}}\lambda_t^{nr}+(1-\upsilon)L_t W_t^{\frac{1+\lambda_w}{\lambda_w}}\lambda_t^{o},\\ f_t^1 &= f_t^2+\eta_t^{\mathrm{w}},\end{aligned}$$

with η_t^{w} representing a wage markup shock.

3.2.3 Firms

3.2.3.1 Final good sector

Firms in this sector produce a final good, which they sell to households and the government, combining a continuum of differentiated goods denoted by $j \in [0,1]$ in a competitive market. The technology of this firm is

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{1}{1+\lambda_p}} \right)^{1+\lambda_p},$$

where λ_p is the markup in the goods market. The demand for intermediate goods and the price of the final good are given, respectively by

$$Y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\frac{1+\lambda_p}{\lambda_p}} Y_t, \quad P_t = \left(\int_0^1 P_t(j)^{-\frac{1}{\lambda_p}} \right)^{-\lambda_p}. \tag{3.4}$$

3.2.3.2 Intermediate sector

Intermediate firm j has monopolistic power, produces according to a Cobb-Douglas technology using capital and a bundle of the labor provided by the households. The production function is given by

$$Y_t(j) = \epsilon_t^a \left(\overline{K}_t(j) \right)^{\alpha} L_t(j)^{1-\alpha} - \Phi,$$

where $\overline{K}_t(j) = z_t K_{t-1}(j)$, Φ is a fixed cost, the productivity shock follows $Ln\left(\epsilon_t^a\right) = \rho_a Ln\left(\epsilon_{t-1}^{\mathrm{a}}\right) + \eta_t^a$ and the labor bundle is $L_t(j) = \left(\int_0^1 \left(L_t^s(j) \right)^{\frac{1}{1+\lambda_w}} ds \right)^{1+\lambda_w}$.

Cost minimization of production and labor cost by firm j yields the following demand for capital, labor and its varieties:

$$\begin{aligned} r_t &= \alpha \epsilon_t^{\mathrm{a}} mc_t \overline{K}_t^{o^{\alpha-1}} L_t^{1-\alpha}, \\ W_t &= \epsilon_t^{\mathrm{a}} mc_t (1-\alpha) \overline{K}_t^{o^{\alpha}} L_t^{-\alpha}, \\ L_t^s(j) &= L_t(j) \left(\frac{W_t^s}{W_t} \right)^{-\frac{1+\lambda_w}{\lambda_w}}, \end{aligned}$$

where mc_t is the marginal cost and the aggregate wage is $W_t = \left(\int_0^1 \left(W_t^s \right)^{-\frac{1}{\lambda_w}} \right)^{-\lambda_w}$.

3.2.4 Price setting

Intermediate firms set prices to maximize profits. As with wages, prices are not fully flexible and only a fraction, $\left(1-\theta_p\right)$, of intermediate firms can change prices in every period. Firms that do not receive the random price-change signal index their prices to price inflation by $P_t(j) = \pi_{t-1}^{\gamma_p} P_{t-1}(j)$. The problem of the firm is to choose its price taking into consideration the exogenous price rigidity and the demand for its product (given by (3.4)) as follows:

$$\max_{P_t(j)} E_t \left[\sum_{\tau=0}^{\infty} \left(\beta\theta_p\right)^{\tau} \frac{\lambda_{t+\tau}^{o}}{\lambda_t^{o}} \left(\frac{\prod_{s=1}^{\tau} \pi_{t+s-1}^{\gamma_p}}{P_{t+\tau}} P_t(j) - mc_{t+\tau} \right) Y_{t+\tau}(j) \right],$$

where γ_p is the price indexation parameter and mc_t is the marginal cost, to be solved endogenously. The solution to this problem can be written recursively as

$$\begin{aligned}
g_t^1 &= \lambda_t^{\mathrm{o}} \frac{P_t^*}{P_t} Y_t + \beta\theta_p \frac{P_t^*}{P_t} \mathrm{E}_t \left[g_{t+1}^1 \frac{P_{t+1}}{P_{t+1}^*} \left(\frac{\pi_t^{\gamma_p}}{\pi_{t+1}} \right)^{-\frac{1}{\lambda_p}} \right], \\
g_t^2 &= \beta\theta_p \mathrm{E}_t \left[g_{t+1}^2 \left(\frac{\pi_t^{\gamma_p}}{\pi_{t+1}} \right)^{-\frac{1+\lambda_p}{\lambda_p}} \right] + \lambda_t^{\mathrm{o}} mc_t Y_t, \\
g_t^1 &= \left(1+\lambda_p\right) g_t^2 + \eta_t^{\mathrm{p}},
\end{aligned}$$

with η_t^{p} representing a price markup shock.

3.2.5 Government

The government expenditure is assumed to wander randomly around its steady state, that is, $G_t = G_{ss}\epsilon_t^G$, with $Ln\left(\epsilon_t^{\mathrm{G}}\right) = \rho_G Ln\left(\epsilon_{t-1}^{\mathrm{G}}\right) + \eta_t^G$. Government income is represented by taxes collected from both types of households and bonds issued to optimizer households. The government budget constraint is given therefore by $G_t + \frac{B_{t-1}}{\pi_t} = T_t + \frac{B_t}{R_t}$.

3.2.6 Monetary authority

Monetary policy is set according to a generalized Taylor rule. Specifically, the central bank adjusts the nominal interest rate, in a smoothed way, in response to developments in inflation and economic activity as in the following:

$$\frac{R_t}{R_{ss}} = \left(\frac{R_{t-1}}{R_{ss}}\right)^{\rho_R} \left(\left(\frac{\pi_t}{\pi_{ss}}\right)^{\psi_1} \left(\frac{Y_t}{Y_t^p}\right)^{\psi_2}\right)^{1-\rho_R} \left(\frac{\frac{Y_t}{Y_{t-1}}}{\frac{Y_t^p}{Y_{t-1}^p}}\right)^{\psi_3} \epsilon_t^r.$$

$Ln\left(\epsilon_t^r\right) = \rho_r Ln\left(\epsilon_{t-1}^{\mathrm{r}}\right) + \eta_t^r$ is the monetary shock, ρ_R determines interest rate smoothing and Y_t^p is the natural or potential output, i.e. the output reached in the economy without nominal frictions and in which all households have access to financial markets.

3.2.7 Aggregation

Aggregate values for consumption, bonds, capital, dividends and investment are given, respectively by

$$\begin{aligned} B_t &= (1-\vartheta) B_t^o, \qquad K_t = (1-\vartheta) K_t^o, \\ Div_t &= (1-\vartheta) Div_t^o, \qquad I_t = (1-\vartheta) I_t^o, \\ C_t &= \vartheta C_t^{\mathrm{nr}} + (1-\vartheta) C_t^{\mathrm{o}}. \end{aligned}$$

3.2.8 Parameterization and solution strategy

Most of the parameters mirror those estimated by Smets and Wouters (2003) (tables 3.1 and 3.2). The only exceptions are the parameters representing the response of the interest rate to inflation and output gap. These parameters follow Smets and Wouters (2007) where the authors assume zero inflation at the steady state.

The model is solved using a second-order approximation, which as mentioned more detailed in Section 3.4, yields a more accurate approximation of the welfare functions. Dynare (Adjemian et al., 2011) provided the numerical solution to the model while the toolkit of Guerrieri and Iacoviello (2015) helped with the construction of the impulse-response functions that take into account the zero lower bound.

3.3 Dynamic responses

This section presents the dynamic effects of the interaction between wage rigidity and financially constrained households, with and without a binding zero lower bound (ZLB). Figures 3.1 to 3.11 show the response of several key macroeconomic

Table 3.1: Parameters for the structural equations

Parameter	Value	Description
α	0.30	share of capital
β	0.99	discount factor
G_{ss}	0.36	steady state government expenses
γ_p	0.47	price indexation
γ_w	0.76	wage indexation
h	0.57	habit formation
λ_p	0.37	goods markup
λ_w	0.5	labor markup
ω	1	disutility of labor
Φ	0.82	fixed cost
ψ	0.17	scale parameters
ψ_1	2	response to inflation
ψ_2	0.08	response to output gap
σ_c	1.35	1/EIS
σ_l	2.4	Frisch elasticity
τ	0.025	depreciation
υ	0	fraction of hand-to-mouth households
φ	6.77	scale parameters
θ_p	0.91	price rigidity
θ_w	0.74	wage rigidity

Table 3.2: Parameters for the shocks

Parameter	Value	Description
ρ_a	0.82	autoregression coefficient for the technology shock
ρ_b	0.86	autoregression coefficient for the preference shock
ρ_G	0.95	autoregression coefficient for the government shock
ρ_r	0.6	autoregression coefficient for the monetary shock
ρ_I	0.93	autoregression coefficient for the investment shock
ρ_L	0.89	autoregression coefficient for the labor shock
ρ_R	0.81	interest rate smoother
σ_a	0.120	standard deviation of the technology shock
σ_b	0.067	standard deviation of the preference shock
σ_G	0.065	standard deviation of the government shock
σ_I	0.017	standard deviation of the investment shock
σ_L	0.704	standard deviation of the labor shock
σ_r	0.016	standard deviation of the monetary shock
σ_{η^p}	0.032	standard deviation of the price markup shock
σ_{η^w}	0.058	standard deviation of the wage markup shock

variables after productivity, labor, investment, monetary and demand shocks.[6] Each figure depicts four scenarios combining high and low wage rigidity with different degrees of asset market participation. Specifically, solid lines represent a high level of wage flexibility ($\theta_w = 0.3$) while dashed lines depict a low level of wage flexibility ($\theta_w = 0.75$).[7] In addition, circle-marked lines represent the case of full market participation ($\upsilon = 0$) while unmarked lines amount to the case when 70% of households are financially constrained ($\upsilon = 0.7$).[8]

3.3.1 Positive Productivity Shock

Inflation responds negatively in all four scenarios to a positive productivity shock (figures 3.1 to 3.3). The responses are almost identical when the ZLB is not binding, except in the case of high wage flexibility and a high fraction of financially constrained households. In that case, we observe a greater fall and a faster recovery. However, when the ZLB is binding, a high level of wage flexibility amplifies the fall in inflation, marginally in an economy with full participation in the asset market, but considerably when a significant fraction of households do not have access to the financial system.

The behavior of inflation determines to a large extent the response of the interest rate. After a positive productivity shock, the nominal interest rate hits the ZLB almost immediately, reaching it sooner with high wage flexibility and even more so when this flexibility is combined with a high fraction of hand-to-mouth households. Once in the ZLB, the interest rate stays in it for a longer time when there is full participation in the asset market and low wage flexibility. Comparatively, the nominal interest rate returns to be positive, two periods in advance, when the fraction of hand-to-mouth households is high, regardless of the level of wage flexibility. This behavior changes when the interest rate never reaches the ZLB. In this scenario, more wage flexibility calls for a stronger response from the interest rate (stronger in the presence of financial constraints) and, as seen in the

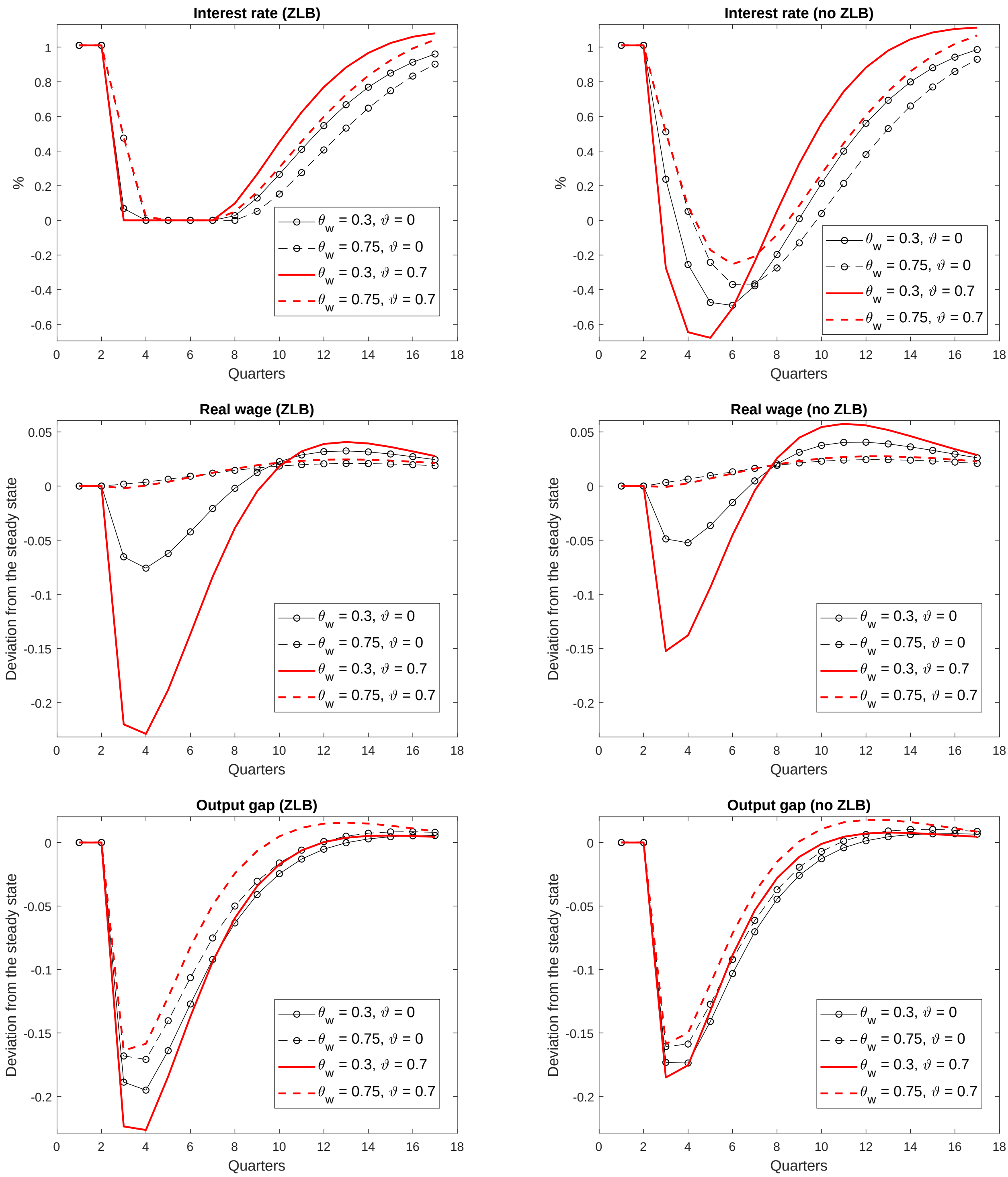
[6] The response to a monetary shock is not presented here because its behavior is similar to the one observed in the case of a productivity shock. The impulse-response for a monetary shock and a government can be found in Appendix 3.6.

[7] A level of wage rigidity of $\theta_w = 0.75$, translates to a duration of wage spells of four quarters on average.

[8] I used 70% as the share of hand-to-mouth households to highlight more clearly the implications of financial constraints. This value is near to the estimates in the literature. The value I chose is also intended to cover those households that have access to financial markets but do not use their financial services. In other words, to try to include those households that, despite having a bank account, do not use it to save. The fraction of these households is more difficult to measure, but some anecdotal evidence suggests that, at least in developing countries, the proportion of households in this category is not negligible.

Figure 3.1: Response to a positive productivity shock - I

Binding zero lower bound | Not binding zero lower bound



figure, in general, the interest rate is more stable when there is a large fraction of hand-to-mouth consumers and wage is relatively rigid.

Consumption is one of the aggregates that shows the greatest change in its dynamic response once the model incorporates households with differentiated access to the financial market. In a scenario with full asset market participation, aggregate consumption responds positively to a positive productivity shock. The hump-shaped response is common in the literature and, as seen in Figure 3.2, is essentially independent of the level of wage rigidity. The response of aggregate consumption is reversed, however, when a fraction of households have financial constraints. When this is the case, aggregate consumption decreases drastically and it is clear that an increase in wage flexibility substantially increases the volatility of this aggregate. Figure 3.2 shows that the effect of the interest rate on aggregate consumption is relatively minor except in the case of high wage flexibility and a high degree of financial restrictions. In this case, the unrestricted nominal interest rate helps mitigate the drop in aggregate consumption.

The behavior of hand-to-mouth households explains the sharp contrast in the response of aggregate consumption between the scenarios of full and limited participation in the financial market. As seen in the figure, the consumption of non-financially constrained households (optimizers) increases in all cases after a productivity shock. The figure also highlights that greater wage flexibility decreases optimizer consumption variability, as intuition suggests, but increases it to a large extent in the case of hand-to-mouth households. When the ZLB is not binding, the nominal interest rate helps to significantly reduce the differences in the optimizers' consumption responses for the different degrees of wage flexibility, given the fraction of financially constrained households. This finding attests to the importance of considering the ZLB when departing from the assumption of total participation in the financial market.

The behavior of the real wage explains in part the response of aggregate consumption. In an economy with high wage rigidity (and also price rigidity), real wages essentially do not respond to shocks in productivity, regardless of the fraction of hand-to-mouth households. However, when a fraction of households does not have access to financial markets, greater wage flexibility amplifies the decrease in real wages. Similar to the case of consumption, a non-active ZLB helps to mitigate the negative response of the real wage.

Although this paper does not consider this aspect, the real wage response highlights the far-reaching distributional implications of wage flexibility when the assumption that the income of a fraction of households corresponds solely

Figure 3.2: Response to a positive productivity shock - II

Binding zero lower bound | Not binding zero lower bound

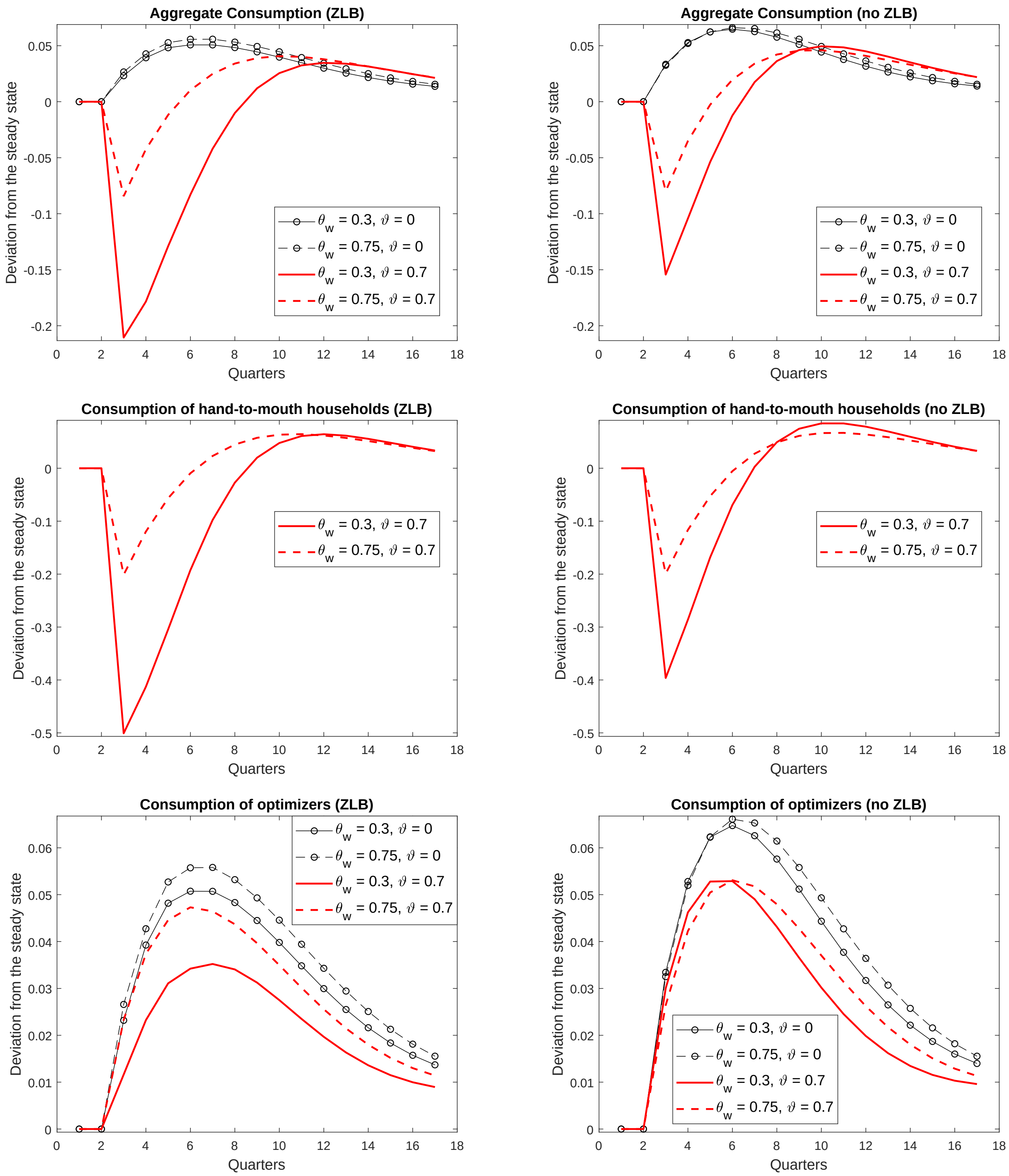
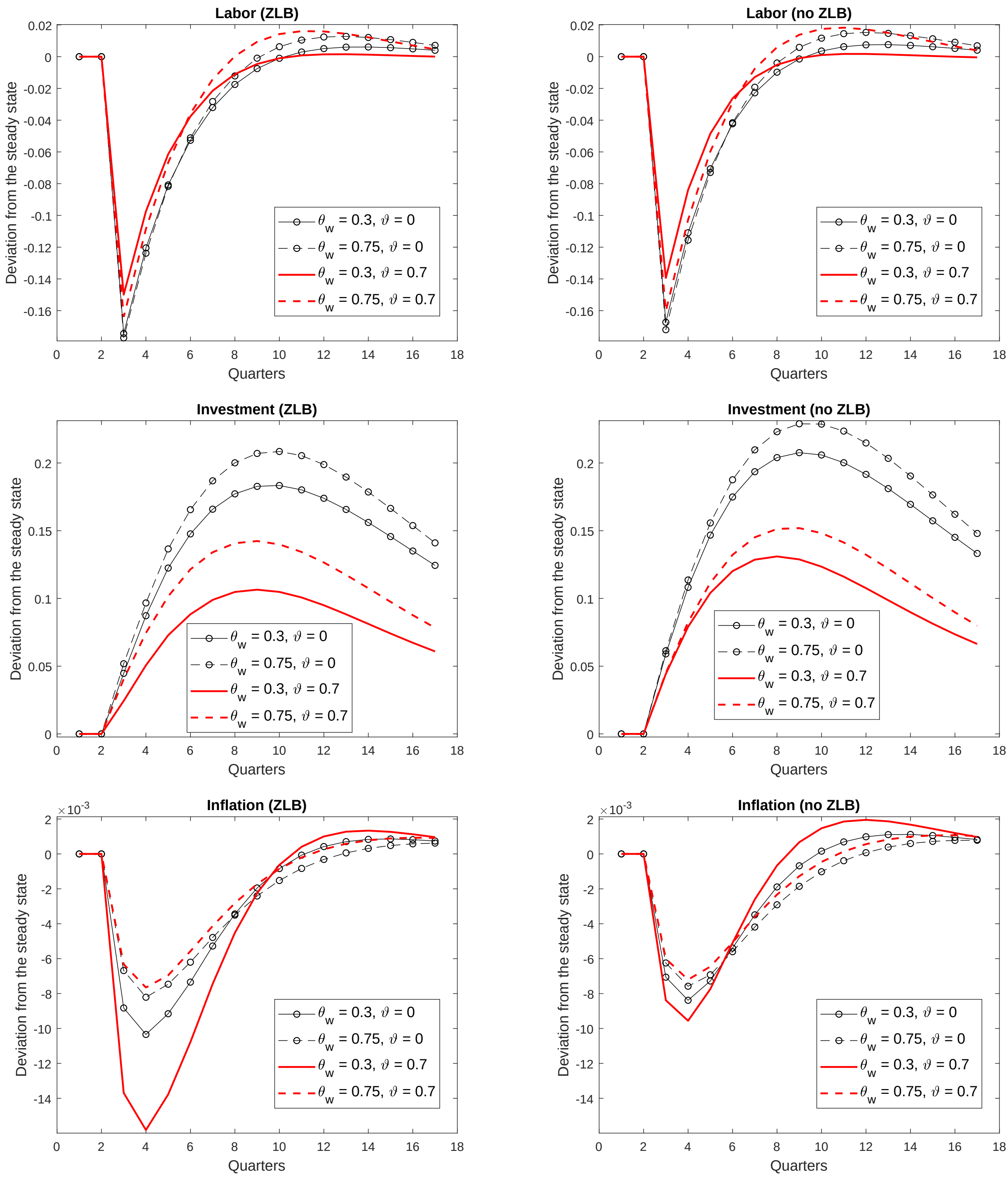


Figure 3.3: Response to a positive productivity shock - III

Binding zero lower bound | Not binding zero lower bound



to their labor income replaces the assumption of full participation in the financial market.

There are no notable differences in the response of labor to a productivity shock despite different assumptions about wage flexibility, access to financial markets or the behavior of the nominal interest rate. The decrease observed in labor, however, contributes to the generation of a negative output gap (both output and potential output increase, but the last one does so to a greater extent). The response of the output gap highlights again the implications of reaching the ZLB. When the lower limit is not binding, the reaction of the output gap is similar in economies with different degrees of wage flexibility given the fraction of hand-to-mouth households considered. When the ZLB is active, this is no longer the case and the output gap shows a stronger negative response for economies with financially constrained households and a higher level of wage flexibility.

3.3.2 Negative Demand Shock

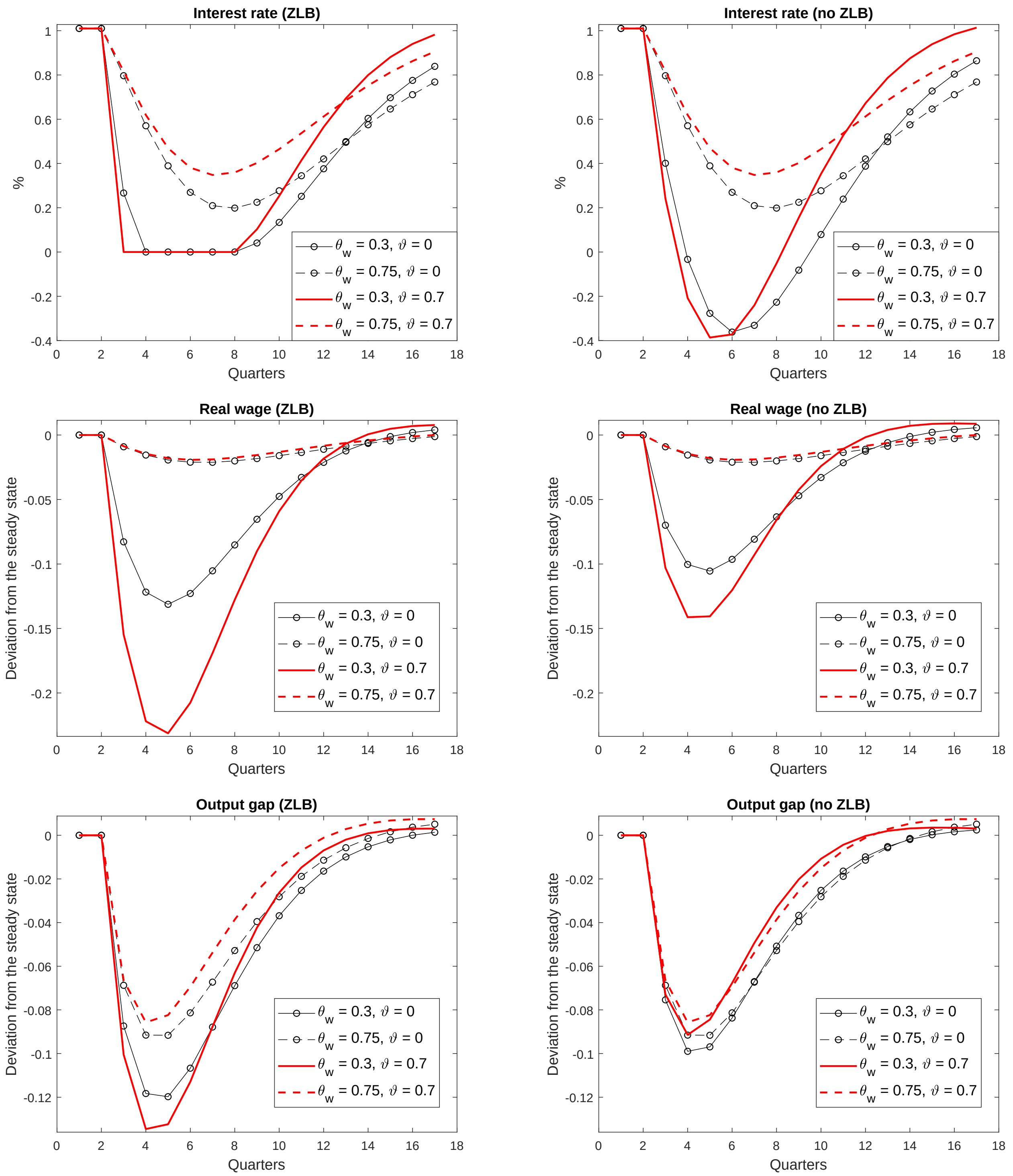
The dynamic responses of most of the variables to a negative demand shock are similar to those observed after a positive productivity shock. However, there are notable differences as shown in figures 3.4 to 3.6. Although I calibrated the shock so that the ZLB becomes binding during the same number of periods as in the case of the productivity shock, the figures show that, in contrast with the effect of the latter, after a negative demand shock, the interest rate reaches the lower limit only when wage flexibility is high. In this case, the interest rate reaches the lower limit more quickly when households with financial restrictions are considered, exhibiting, in turn, a speedier recovery. We also observe a faster recovery when nominal wage flexibility is low and we assume the presence of a large fraction of hand-to-mouth households.

After a negative demand shock, under a particular combination of parameters, mainly the assumption about the degree of rigidity of the nominal wage, it seems that the model is capable of reproducing the behavior of real wages observed in three of the last four recessions. As we can see in Figure 3.4, in recessions generated by a demand shock, and importantly, when assuming that nominal wages are very rigid, real wages only shows a slight reduction with respect to their steady state. On the contrary, if we suppose that nominal wages are more flexible, these results disappear and we observe a significant decrease in real wages.

The responses of the main variables, such as in the case of a productivity shock, are mostly the same when wages are highly rigid and all households have

Figure 3.4: Response to a negative demand shock - I

Binding zero lower bound — Not binding zero lower bound



full access to financial markets. However, Figure 3.4 shows that once the financial restrictions are in force, the increase in wage flexibility generates a decrease in real wages twice as large compared to the scenario of full participation in the asset market. This discrepancy intensifies when the ZLB restricts the nominal interest rate.

The responses of output and output are similar to those of the real wage. Both measures of production decrease considerably, and the amplifying effect of the interaction between more wage flexibility and the presence of hand-to-mouth households when the ZLB is binding is clear. Interestingly, having a fraction of hand-to-mouth households, when wages are more rigid, makes the output gap less sensitive to a demand shock. When the ZLB is not binding, differences in the response of the output gap between the four scenarios almost disappear and it becomes evident that having a fraction of households financially constrained helps stabilize the economy regardless of the degree of wage flexibility.

Consumption of both optimizers and hand-to-mouth households decreases in response to a negative demand shock and, as expected, greater wage flexibility significantly increases the volatility of the response of the latter group. It is noteworthy that when the ZLB is active, the response of aggregate consumption does not depend on the degree of wage flexibility provided that all households have access to financial markets.

The response of inflation when the ZLB is not active is almost indistinguishable for the two degrees of wage flexibility considered, given the level of participation in the financial market. However, this is not the case when the interest rate hits the ZLB, in which case the greater wage flexibility increases the magnitude of the negative response, but it does so to a greater extent in the presence of financial constraints.

3.3.3 Positive labor and investment shocks

After a positive labor shock, the labor response is similar across the four scenarios, although slightly more volatile when the interest rate is not restricted by the lower bound (figures 3.7 to 3.9). As with the shocks mentioned above, the responses of inflation and output gap are exacerbated when the counterweight provided by the interest rate is off the table. With respect to the response of most of the rest of the variables, a common occurrence is the similar behavior observed after the shock when wage flexibility is low regardless of the assumption about the percentage of households without access to the financial market.

Figure 3.5: Response to a negative demand shock - II

Binding zero lower bound | Not binding zero lower bound

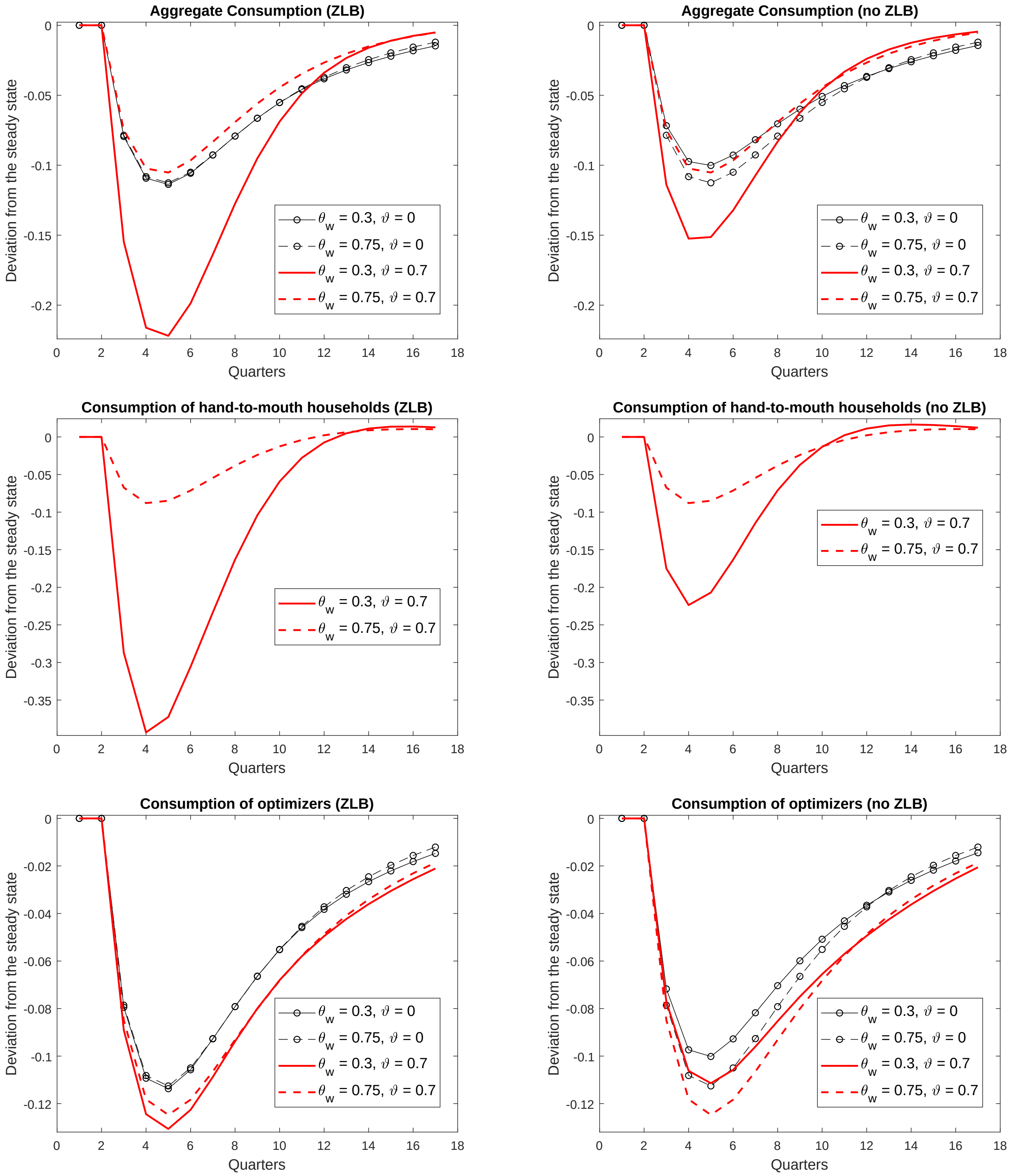


Figure 3.6: Response to a negative demand shock - III

Binding zero lower bound | Not binding zero lower bound

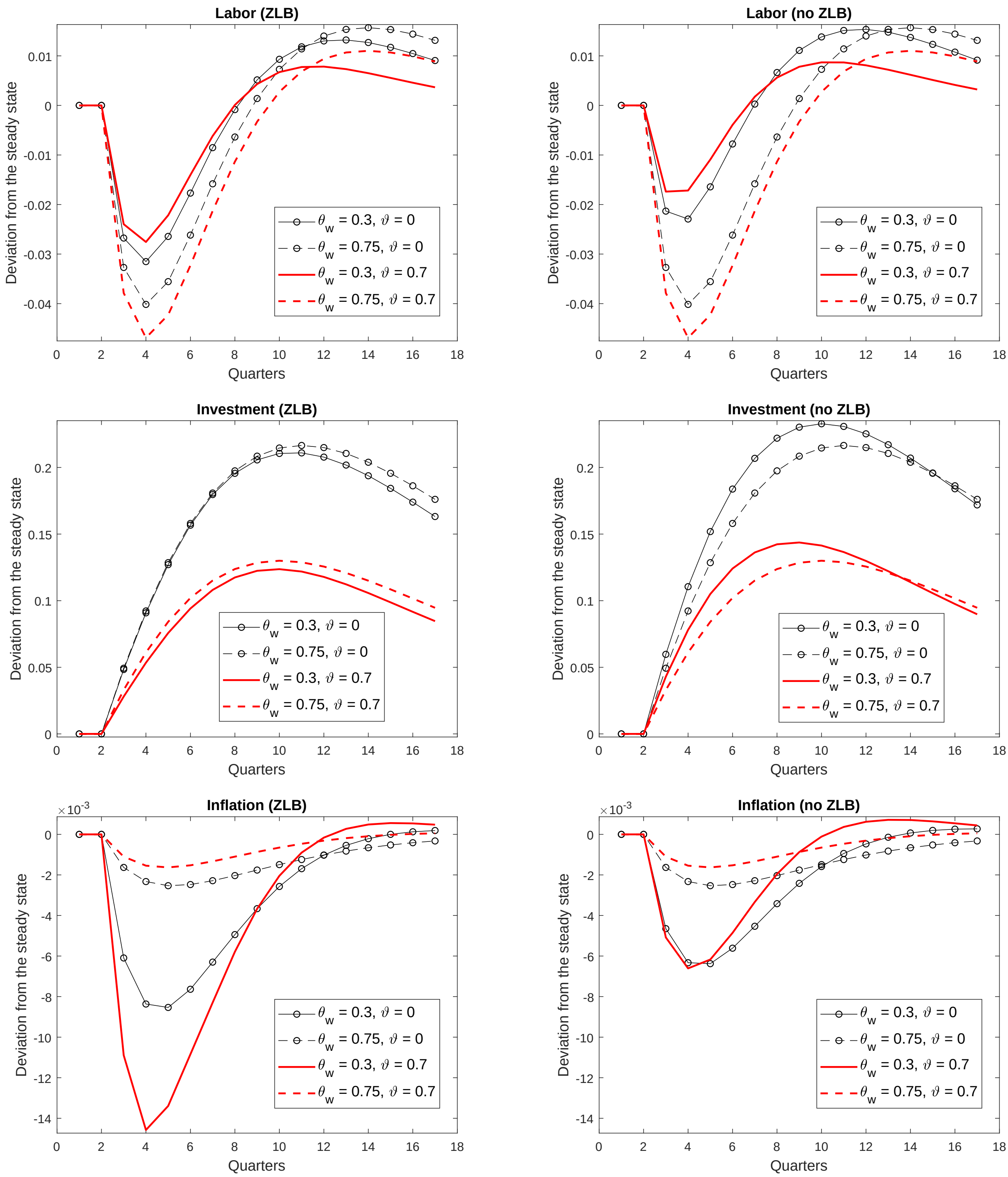
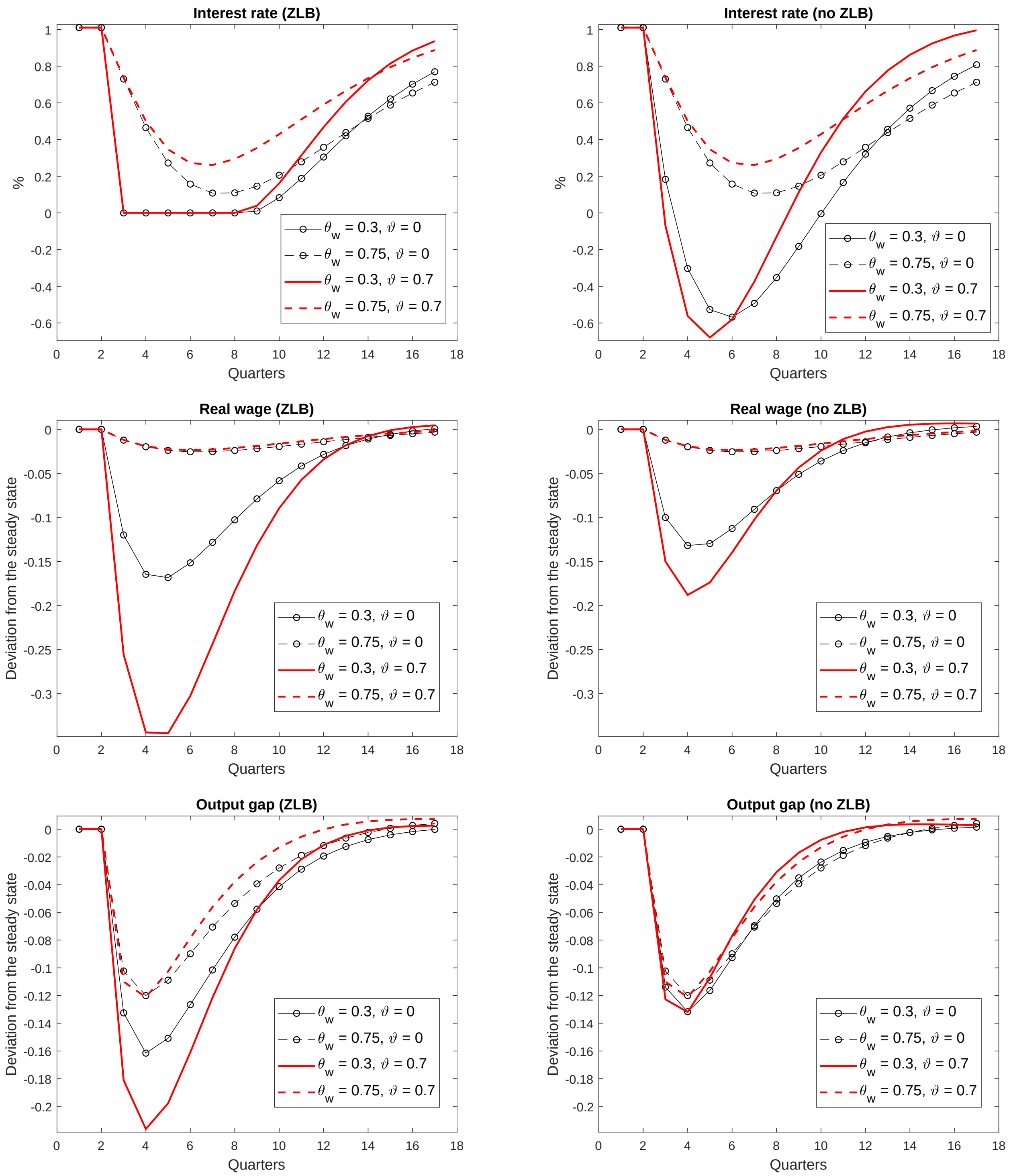


Figure 3.7: Response to a positive labor shock - I

Binding zero lower bound Not binding zero lower bound



The response of aggregate consumption is worthy of mention. Total consumption increases, following a similar dynamic in three of the four scenarios, but shows a considerable decrease in the economy with high wage flexibility and a high percentage of financially restricted households. The fall in consumption is explained to a large extent by the negative response of the consumption of hand-to-mouth households, motivated in turn, by the significant decrease in real wages. In this case, low wage flexibility seems more convenient since, as the figure shows, in the presence of households whose total income corresponds only to labor income, high wage rigidity cushions the decrease in real wages and contributes to an increase in the consumption of hand-to-mouth households.

A positive investment shock, as shown in figures 3.10 and 3.11, highlights the differences in the responses of the two types of households in an economy with financially restricted households.[9] In particular, after an increase in investment due to a decrease in the cost of installing capital, optimizing households increase investment at the expense of their consumption. This behavior is more pronounced when wages are more rigid and a fraction of households do not have access to financial markets. Households without access to the financial market do not face this dilemma and, on the contrary, their consumption increases due to the rise in labor and real wages. As a result, hand-to-mouth households help stabilize aggregate consumption regardless of the degree of wage flexibility.

3.3.4 Summary of the dynamic responses

We can draw several conclusions from the impulse-response functions analyzed. In general, the results of the dynamic responses suggest that the prevailing notion in some policy circles of the stabilizing benefits of greater wage flexibility does not apply when a fraction of households have financial constraints. This is particularly clear for variables such as the real wage, the output gap, consumption and inflation, which showed stronger and more persistent responses after the occurrence of shocks in a scenario of incomplete participation in the asset market. The results also illustrate the critical role of the nominal interest rate since, in most cases, monetary policy can substantially reduce the volatility of the aforementioned variables, provided that the lower bound of the interest rate is not binding.

[9] These figures only show the answers when the ZLB is not binding. A positive investment shock generates a positive response in the nominal interest rate and, therefore, makes it impossible for it to reach the lower limit.

Figure 3.8: Response to a positive labor shock - II

Binding zero lower bound | Not binding zero lower bound

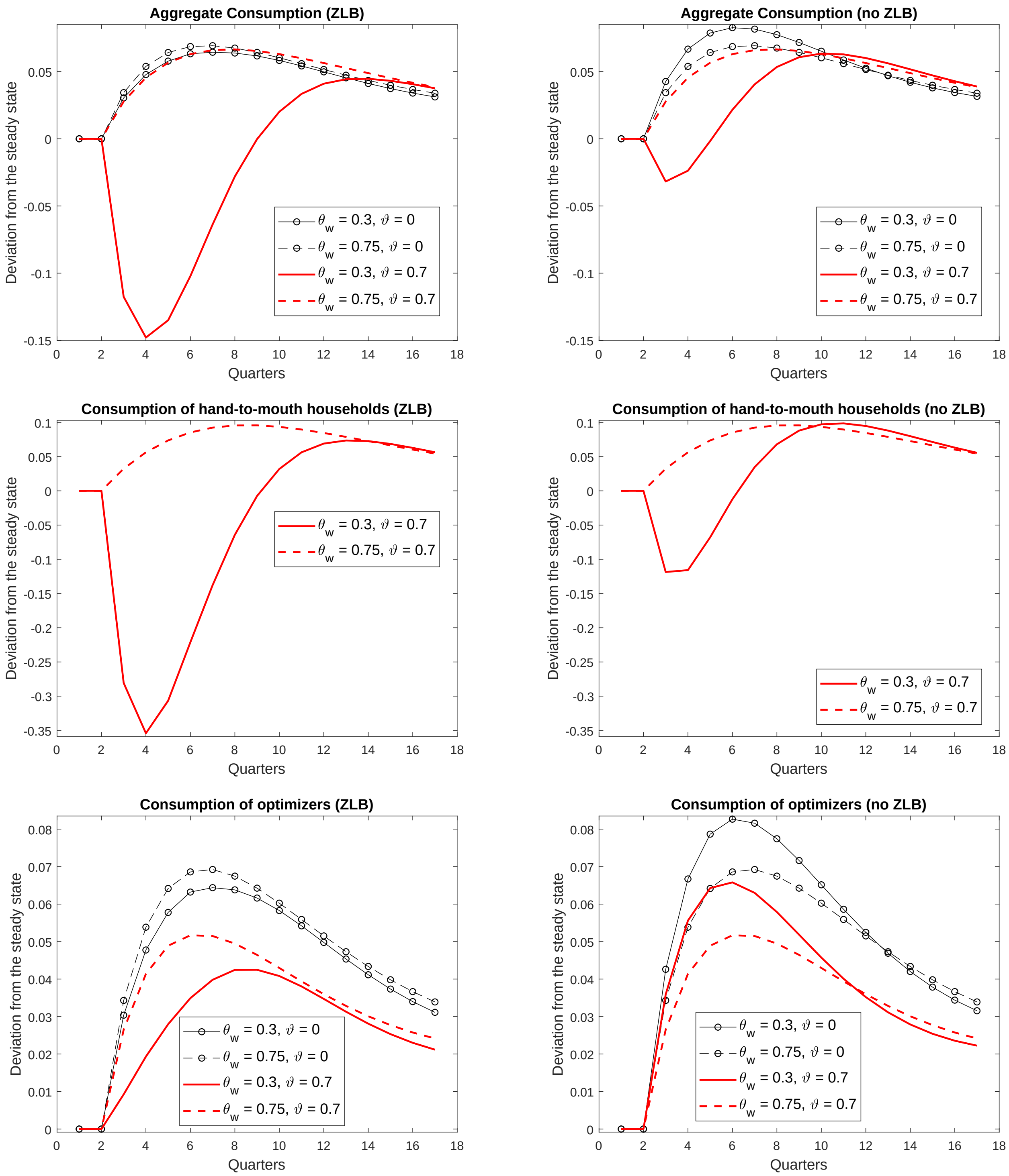


Figure 3.9: Response to a positive labor shock - III

Binding zero lower bound — Not binding zero lower bound

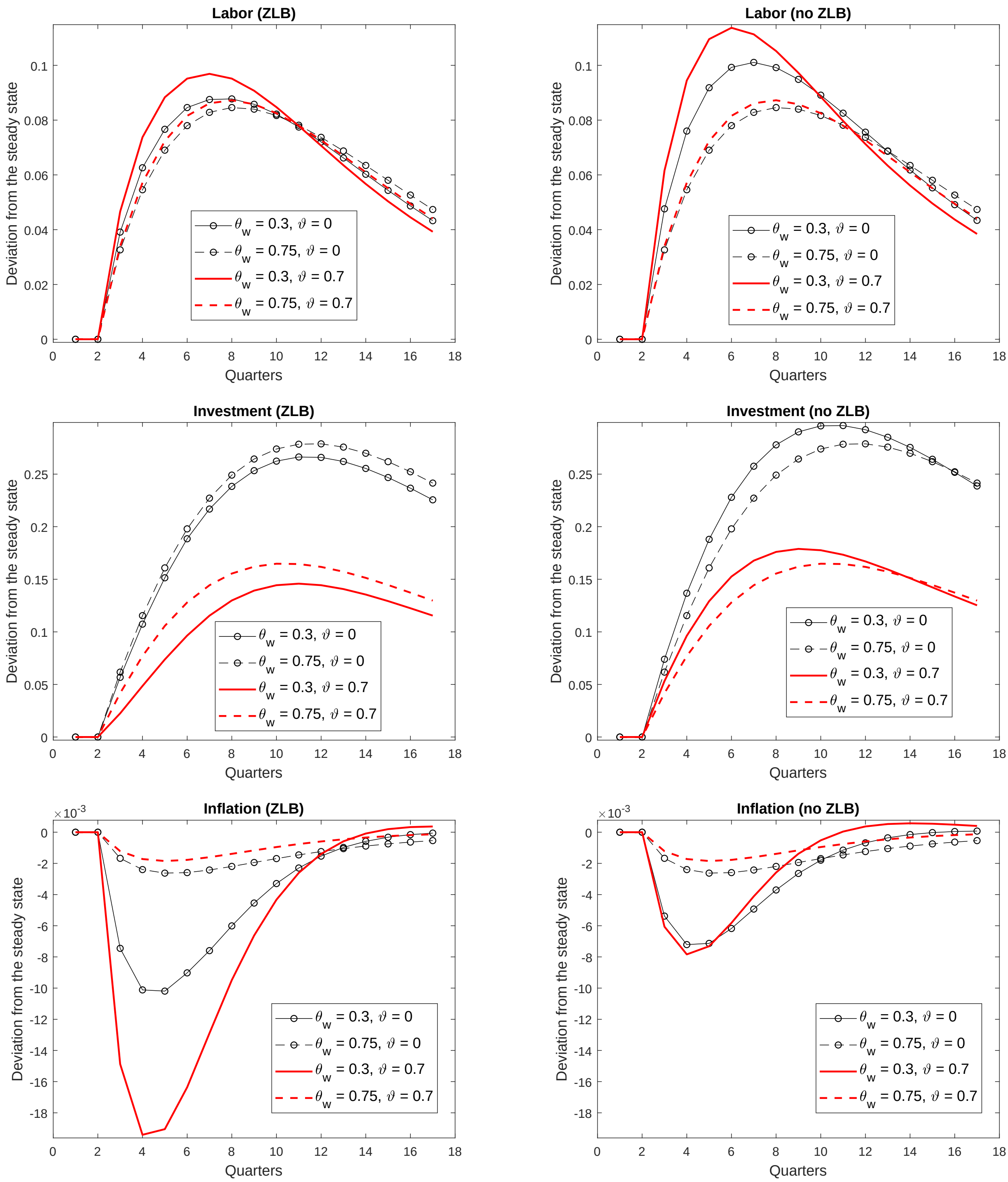


Figure 3.10: Response to a positive investment shock - I

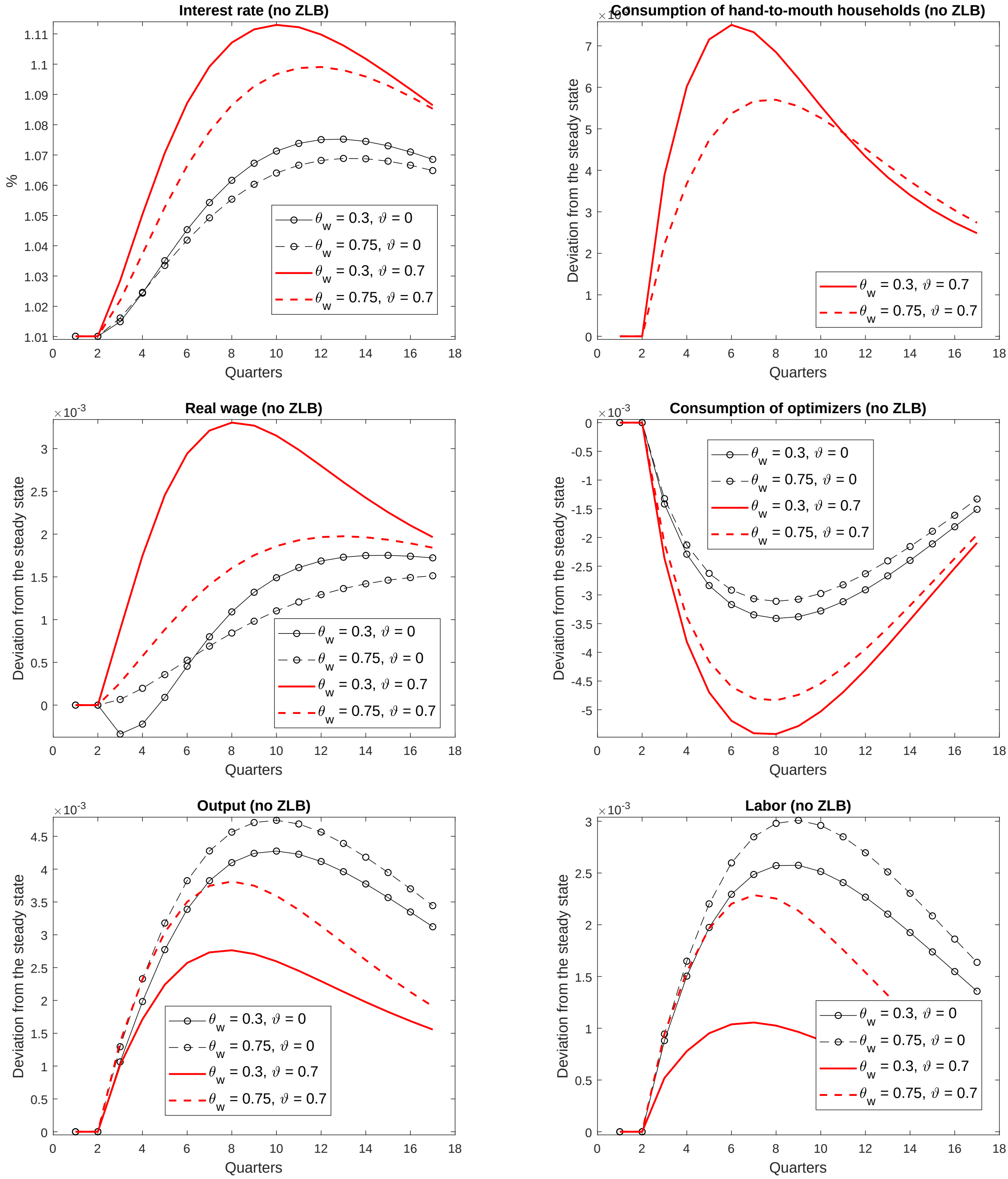
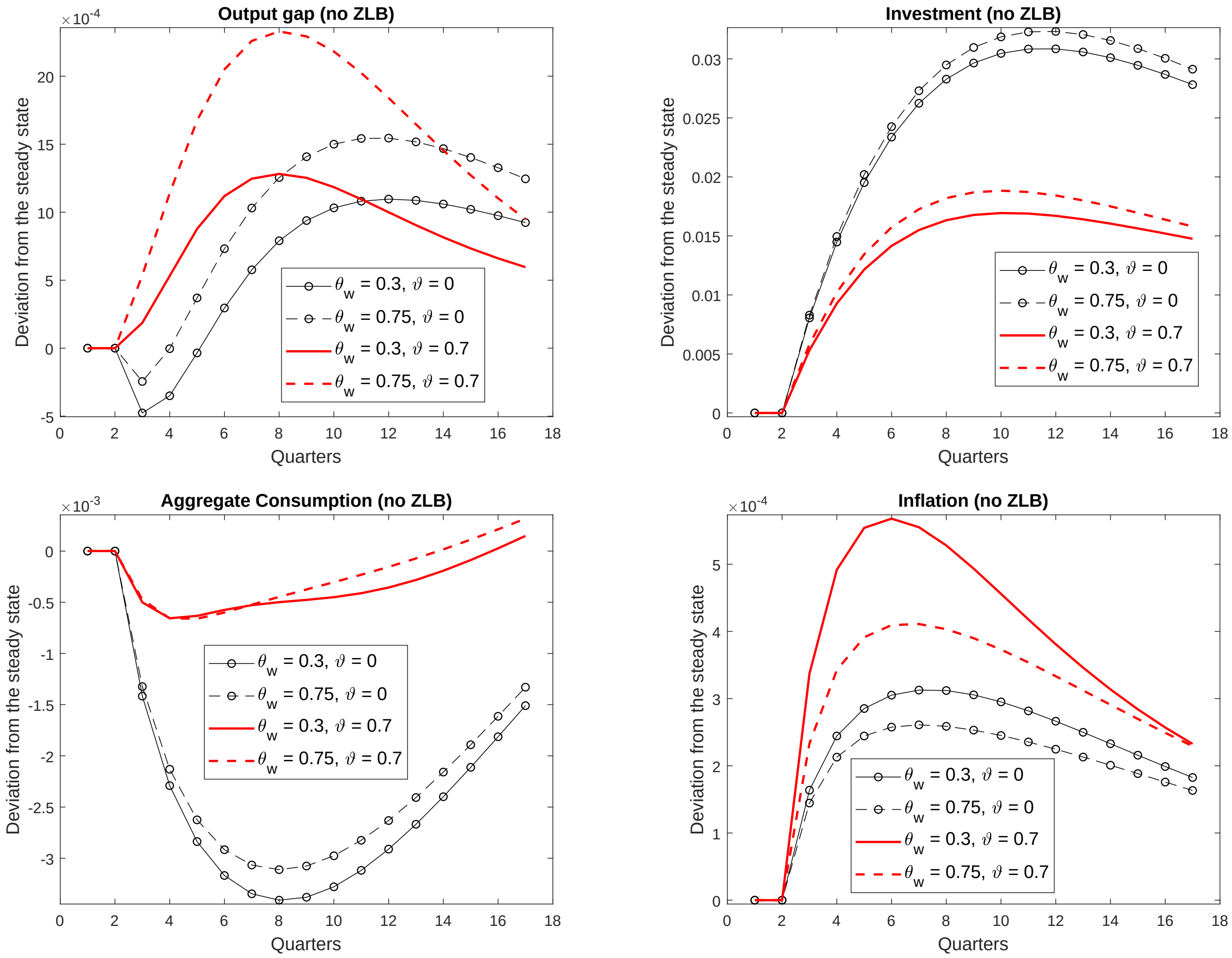


Figure 3.11: Response to a positive investment shock - II



A complete view of the consequences of the interaction of wage rigidity and financial constraints requires the analysis of their combined effects on welfare. This is the subject in the next section.

3.4 Welfare

An analytical expression for the welfare/loss function is not available for the model in this paper. However, given that the model is solved using a second-order approximation, it is possible to perform a formal numerical analysis of welfare that takes into account the effects of the second moments of the shocks on the mean of the variables of interest. The present analysis departs, therefore, from the traditional approach where a quadratic loss function is derived from the second-order approximation of the welfare function and then evaluated using a first-order approximation of the policy functions (or decision rules). As Kim and Kim (2003) show, this approach could yield incorrect results because it ignores some important second-order and higher-order terms of the welfare function. Sometimes, the consequences of overlooking this term in the welfare calculation are of such magnitude that paradoxical results appear, e.g., greater welfare in economies with incomplete markets compared with economies with complete markets (Kim, 1997).

As discussed by Schmitt-Grohé and Uribe (2004), a correct second-order approximation of the welfare function requires a second-order approximation of the policy functions and, additionally, as a byproduct, allows the welfare assessment around the (supposedly) more realistic inefficient stable state.[10]

In this order of ideas, I measure welfare as the weighted average of the utility of Ricardian and hand-to-mouth households,

$$\mathscr{W}_t = E\left[\upsilon U_t^o + (1-\upsilon)U_t^{\text{nr}}\right],$$

with U_t^o and U_t^{nr} given by (3.1) and (3.2), respectively.

As I mentioned, there is no analytical expression for the welfare loss function for the model in this paper. However, it is possible, by analogy, to infer that this function depends on key parameters associated with the frictions in the model and with the variance of price and wage inflation, the output gap, and the gap be-

[10]Traditionally, welfare analysis is carried out around the efficient steady state in which the government, using subsidies, eliminates distortions in the markets of goods and labor created by the monopolistic power of households and firms.

tween the consumption of optimizing and hand-to-mouth households.[11] Taking this into account, I define the loss function as the loss of welfare with respect to the welfare in the steady state,

$$\mathscr{L}_t\left[var(\pi_t),\, var\left(\pi_t^w\right),\, var\left(\frac{Y_t}{Y_t^p}\right),\, var\left(\frac{C_t^o}{C_t^{\mathrm{nr}}}\right);\, \theta_p,\, \theta_w,\, \psi_1,\, \upsilon\right] = \frac{\mathscr{W}_t - \mathscr{W}_{ss}}{\mathscr{W}_{ss}}.$$

The following analysis places particular emphasis on the effect of changes in the parameters related to nominal frictions in wages and prices, in household access to financial markets and in the response of the nominal interest rate to price inflation.

Figure 3.12 shows the mean loss function $\left(\bar{\mathscr{L}}\right)$ as a function of wage flexibility and the fraction of financially constrained households.[12] When all households have access to the financial market ($\upsilon = 0$) the figure shows that, in general, the increase in wage flexibility improves welfare. Specifically, starting with highly rigid wages, increases in wage flexibility improve welfare to a point where the parameter measuring wage rigidity is around 0.6 (implying a duration of wage contracts of 2.5 quarters) and a welfare loss of 0.076 with respect to the steady state. After this minimum point, higher degrees of wage flexibility increase welfare only slightly, generating, when wages are highly flexible ($\theta_w = 0.25$ or an average duration of 1.3 quarters), a loss of welfare of 0.081 with respect to the steady state. These results are in line with what is found in the literature regarding the benefits of greater wage flexibility (see, for example, Galí (2013)).

The benefits, however, disappear when even a small fraction of households face financial constraints. In this case, only starting from scenarios with extreme wage rigidity is it possible to find welfare gains, although small, by increasing wage flexibility. However, after exceeding the "optimal" degree of salary flexibility, the increase in wage flexibility has disastrous consequences for welfare. For example, when 70% of households face financial constraints, the loss of welfare associated with a high level of wage flexibility is almost 40%.

Figure 3.13 shows the mean loss as a function of the degree of wage and price flexibility when all households have access to financial markets (panel A) and when 70% of them have financial constraints (panel B). When there are no financial constraints, the benefits of greater wage flexibility, when accompanied by

[11] Galí (2013), Ascari, Colciago and Rossi (2016) and Walsh (2017) provide derivations of the welfare loss function for models similar to the one presented in this paper but without capital and/or investment.

[12] The rest of the parameters take their benchmark values, in particular, a relatively high price rigidity $\left(\theta_p = 0.91\right)$ and a strong reaction of the interest rate to inflation $\left(\psi_1 = 2\right)$.

Figure 3.12: Welfare losses: wage flexibility and hand-to-mouth households

high price flexibility, are clear. In fact, as the figure shows, relatively high levels of nominal flexibility (in prices and wages) generate a level of welfare that is even higher than that reached in the steady state. Higher levels of nominal rigidity, both for wages and for prices, decrease welfare (weakly) monotonously.

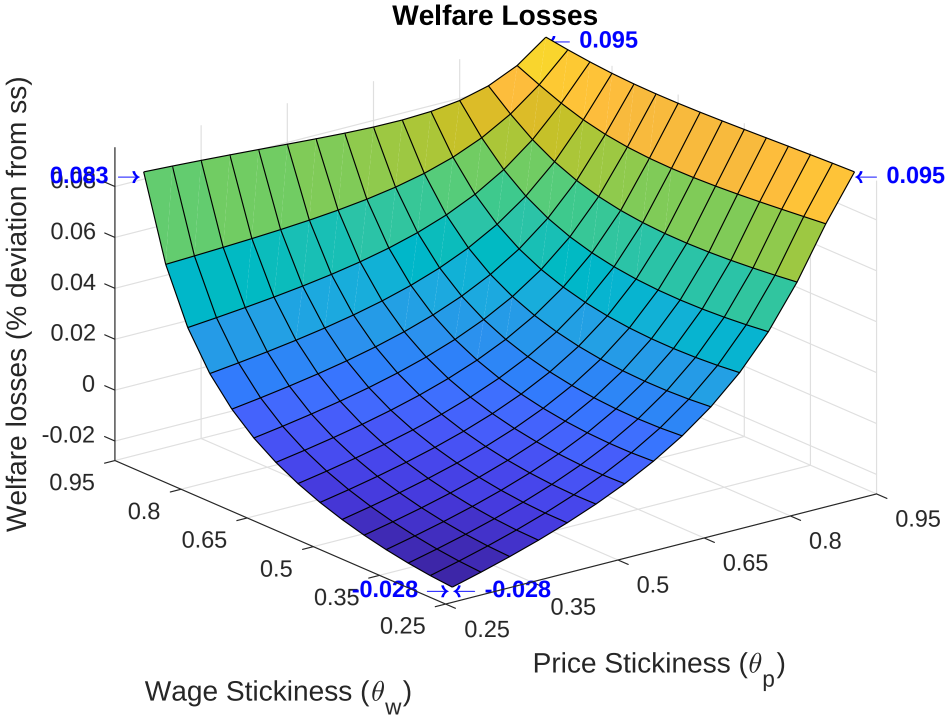
In an economy in which a fraction of the population does not have access to financial markets, greater wage flexibility improves welfare only in the presence of relatively high price flexibility. When price rigidity is around the estimated range commonly found in the literature (around $\theta_p = 0.75$, i.e. with prices that change on average once a year) the benefits of increasing wage flexibility are less obvious, even showing a slight decrease in welfare. With higher degrees of price rigidity, greater wage flexibility is counterproductive in terms of welfare.

Figure 3.14 shows the mean loss as a function of wage rigidity and the strength with which the interest rate responds to price inflation when all households have access to financial markets (panel A) and when 70% are financially restricted (panel B). When considering the weight that the monetary authority gives to the dynamics of inflation, the adverse effect of greater wage flexibility in the presence of financial frictions is more evident. In the traditional model, with full participation in the asset market, greater wage flexibility increases welfare only when

Figure 3.13: Welfare losses: wage an price flexibility

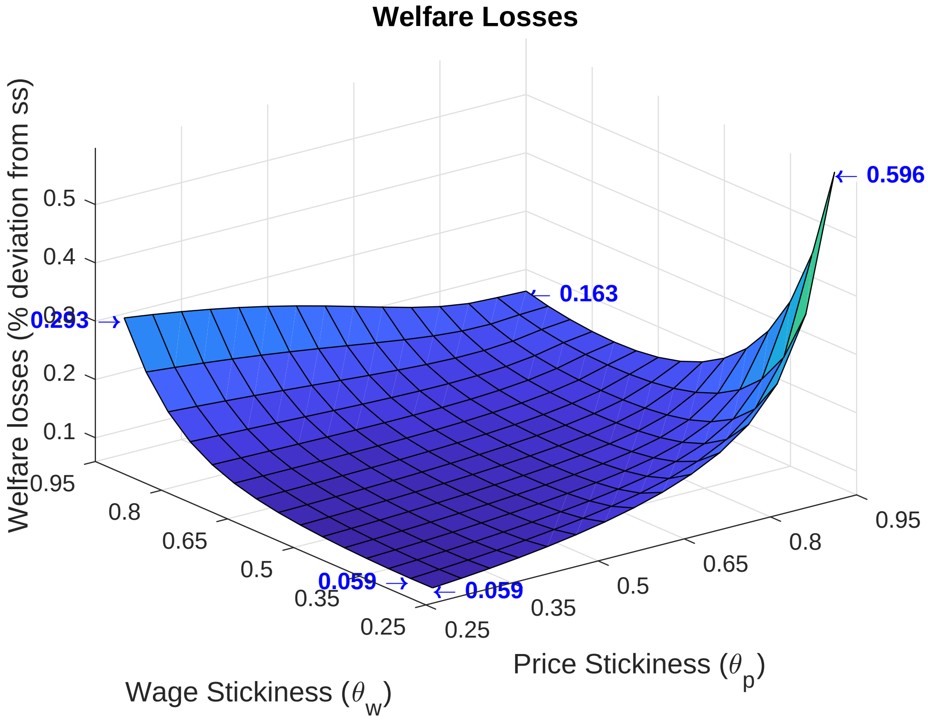
Panel A

Complete asset market participation ($\upsilon = 0$)



Panel B

70% of hand-to-mouth households ($\upsilon = 0.7$)



the monetary authority has a relatively strong response to inflation. The two opposite effects of wage flexibility on welfare explain this result (Galí (2013) found similar results). Specifically, because greater wage flexibility reduces the volatility of the labor, which increases welfare, but at the same time reduces welfare due to higher volatility in price and wage inflation. When the response of the monetary authority to inflation is strong enough, the benefits of greater labor stability prevail.

In contrast, when a fraction of households is hand-to-mouth, although, in general, a stronger response to inflation increases welfare regardless of the level of wage flexibility, the figure shows that for a given level of response to inflation, increasing wage flexibility improves welfare only in the presence of implausibly high initial levels of wage rigidity. Even in that case, the increase in welfare associated with greater wage flexibility is small. On the contrary, there is a considerable decrease in welfare, for all levels of response to inflation, once the "optimal" wage flexibility is exceeded.

In summary, and similar to the analysis of the dynamic response in Section 3.3 the claims in favor of greater wage flexibility are only maintained for a particular set of parameters and when total participation in the asset market is assumed. Even in that case, greater wage flexibility only generates welfare improvements of small magnitude. For most parameter values, and when a fraction of households cannot or do not want to smooth their consumption, an increase in wage flexibility is detrimental to welfare.

3.5 Conclusions

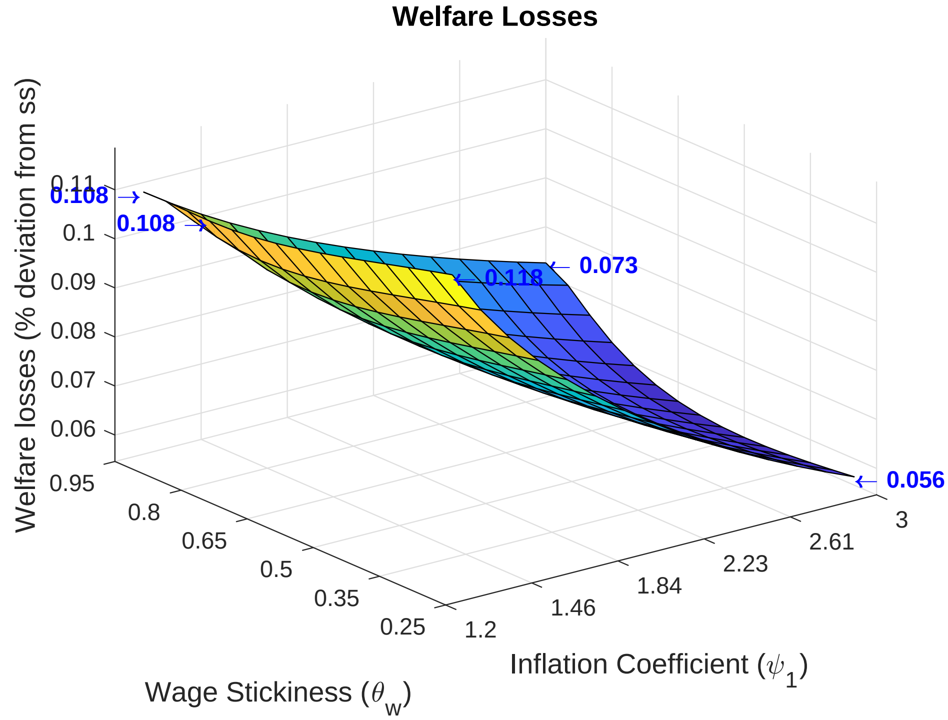
Having mechanisms at hand to help mitigate the real economic effects of recessions is of paramount importance as exemplified by the recent financial crisis. One of the most common policy suggestions to protect, to a certain extent, the economy of shocks is the increase in labor market flexibility, among others, by improving the freedom to negotiate labor contracts at the firm level, eliminating the minimum wage laws and eliminating barriers to changes in wages. This last characteristic, greater wage flexibility, is usually at the center of the discussion because its effects on employment stability seem obvious. However, recent research has shown that the relationship between greater wage flexibility and employment stability is not as direct as intuition suggests.

This paper contributes to this line of research by analyzing the effects of greater wage flexibility on macroeconomic stability and welfare in an economy

Figure 3.14: Welfare losses: wage flexibility and nominal interest rate response to inflation

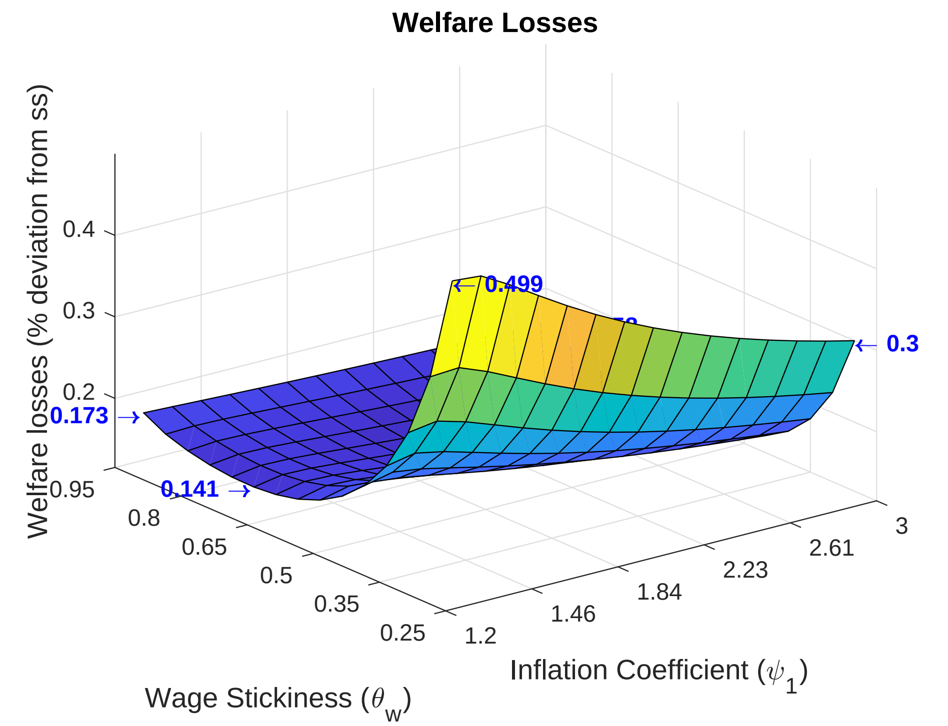
Panel A

Complete asset market participation ($\upsilon = 0$)



Panel B

70% of hand-to-mouth households ($\upsilon = 0.7$)



with nominal frictions and where a fraction of households have financial restrictions. The analysis is based on a calibrated New-Keynesian medium-size DSGE model that includes characteristics that have proven to be essential for understanding the short-term behavior of economic activity and the response of key macroeconomic variables after being affected by shocks.

Two findings stand out. First, the analysis shows that greater wage flexibility is counterproductive to economic stability when some households are financially constrained and, therefore, highly vulnerable to shocks in their current labor income. This result, which raises doubts about the traditional recommendations on the benefits of greater wage flexibility, is even more evident when the monetary policy is ineffective because the nominal interest rate reaches its lower bound. This highlights the relevance of monetary policy in a scenario with financial frictions.

Second, regarding welfare, I found that greater wage flexibility only improves welfare when starting from an implausibly high level of wage rigidity and, even in that case, the gains are small. When even a relatively small fraction of households is financially constrained, increases in wage flexibility have strong negative effects on the entire economy.

The results also confirm the findings in the literature on the benefits of high nominal wage flexibility when accompanied by high price flexibility in a framework of complete market participation. However, this finding must be qualified when households have financial constraints. In this case, greater wage flexibility only improves welfare when accompanied by high price flexibility. With more rigid prices, e.g. changing on average each year (as supported by several empirical studies), the increase in wage flexibility becomes detrimental to welfare.

Finally, I found that when all households have access to credit markets, high wage flexibility improves welfare when the response of the monetary authority to inflation is sufficiently strong. In other words, by responding energetically to changes in inflation, the monetary authority can counteract the negative effects on welfare of the increase in the volatility of inflation, while at the same time maintaining the welfare benefits associated with higher job stability. In contrast, with a fraction of hand-to-mouth households, greater wage flexibility is detrimental to welfare and a strong response of the interest rate to inflation only slightly mitigates its negative effects.

The analysis in this paper highlights the importance of financial inclusion for the welfare of households. The results show that, in general, having access to the financial system generates greater welfare in the economy as a whole, compared to the case in which even a small fraction of households have financial restrictions. The policy recommendation in this regard is clear. It is advisable to take additional measures that encourage the participation of agents in the financial markets, making emphasis on those agents that seem to be more relegated, in particular, women, households in poor countries and those who live in rural areas. Advances in technology, particularly the rapid adoption of cell phones, have helped with this goal and will almost certainly continue to facilitate the interaction between households and financial institutions. In recent decades we have observed significant improvements regarding financial inclusion, but there is still a long way to go.

3.6 Appendix

3.6.1 Response to a positive monetary shock

3.6.2 Response to a positive government shock

Figure 3.15: Response to a positive monetary shock - I

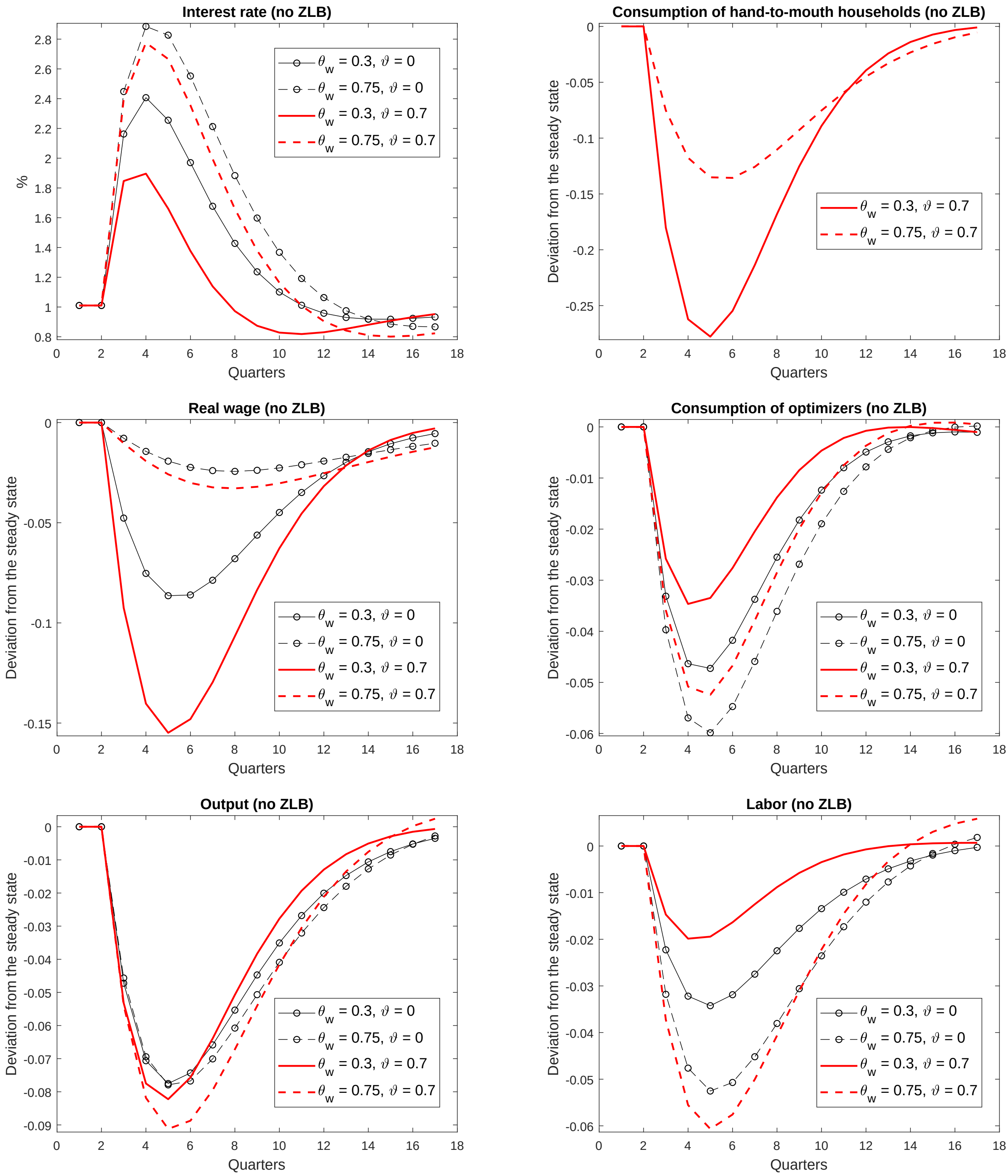


Figure 3.16: Response to a positive monetary shock - II

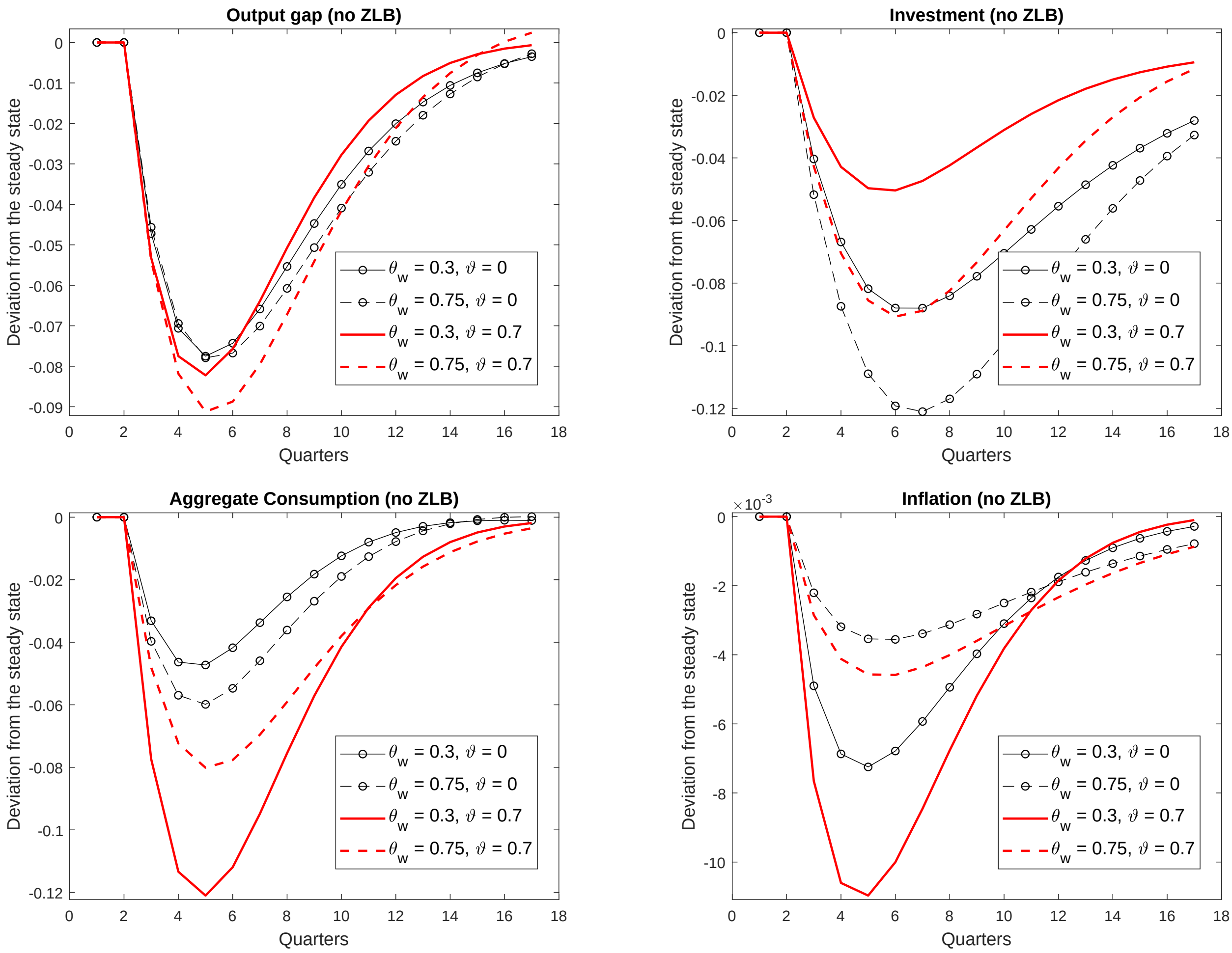


Figure 3.17: Response to a positive government shock - I

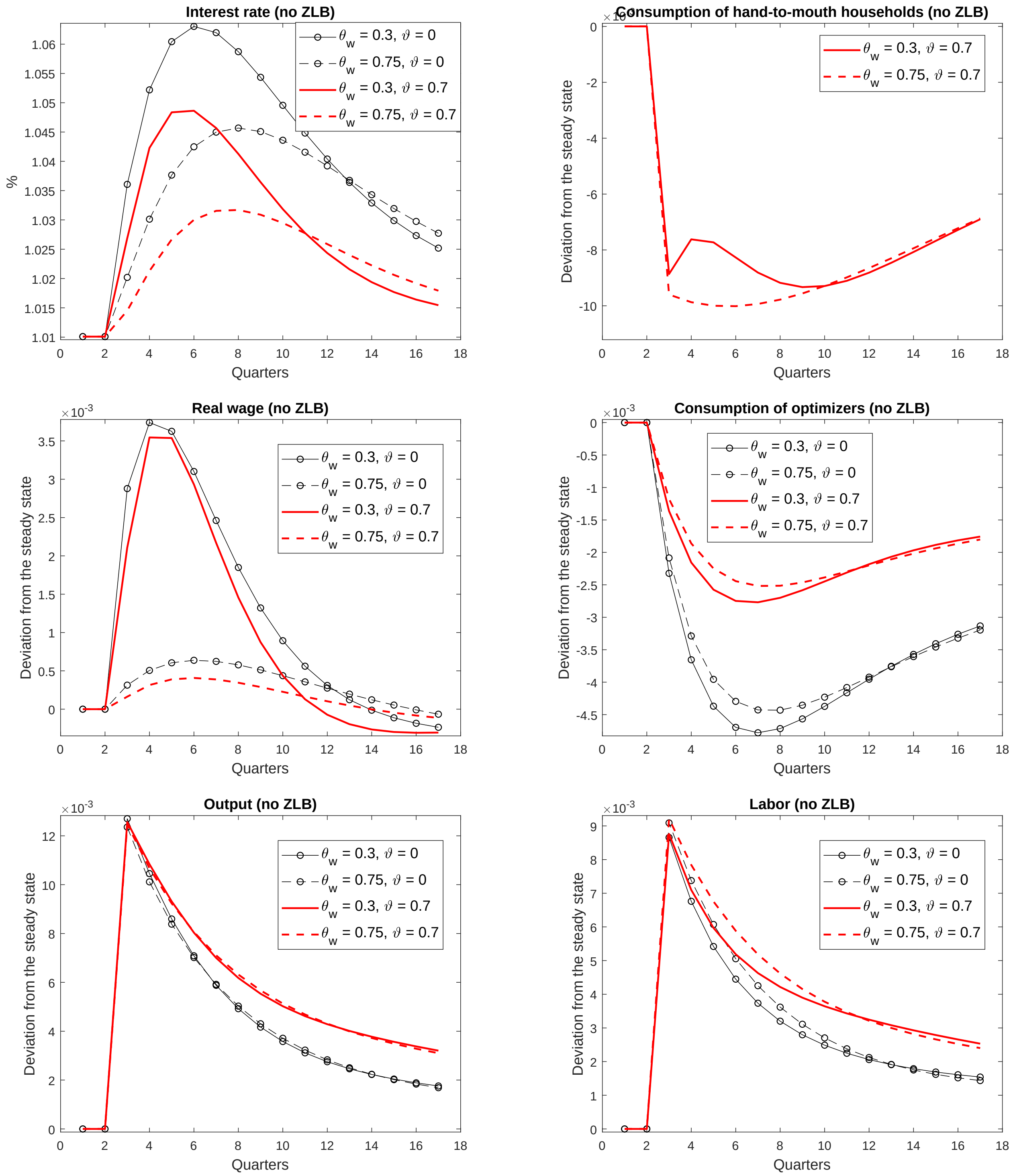
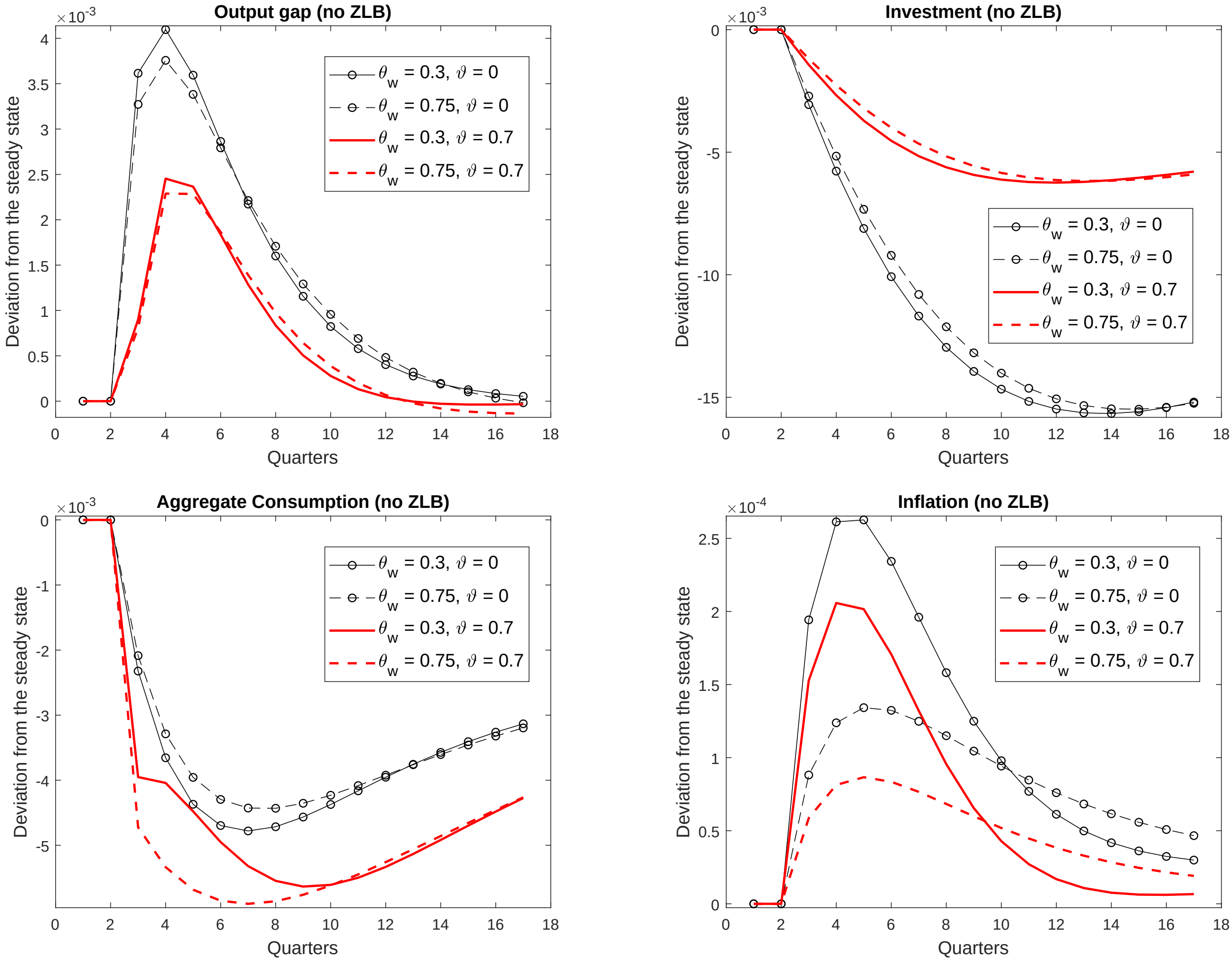


Figure 3.18: Response to a positive government shock - II



Chapter 4

Rigid Wages & Contracts: Time-vs. State-Dependent Wages in the Netherlands

This chapter is based on a joint work with Burak Uras and Nathanael Vellekoop.

4.1 Introduction

Macroeconomists widely accept nominal wage rigidity as an imperfection that may generate substantial fluctuations in unemployment and output in the short term. The existence of nominal wage rigidity also provides a motivation for monetary policy to steer macroeconomic activity. Therefore, traditional Keynesianism and, more recently, New Keynesian literature, emphasize the importance of identifying the degree of nominal wage rigidity in an economy. In this sense, a better understanding of patterns of wage rigidity is essential for uncovering the sources of business cycles and developing optimal policy instruments to handle economic fluctuations.

In this paper, we use a large high-frequency micro-panel dataset on monthly salaries for all employees in the Netherlands to explore the dynamics of nominal wage rigidity. Our research objectives are threefold: (i) We estimate nominal wage rigidity at the industry level and, more importantly, at the worker level. (ii) It is important to highlight that given the unique quality of the data, we decomposed the wage changes of the employees into components that are related to the explicit contractual terms, with the characteristics of the firms and the industry, and with factors associated with macroeconomic conditions. (iii) Finally, by exploiting the detailed structure of the data, we analyze the determinants of nominal wage adjustments. In particular, we study whether in the Dutch economy, both in aggregate terms and disaggregated according to contractual characteristics, nominal wage adjustments are state-dependent or time-dependent.

Research that uses microeconomic data to estimate the degree of nominal wage rigidity has concentrated mainly on uncovering the presence of downward wage rigidities, specifically, in the frequency of wage freezes. Some examples of this line of research are Mclaughlin (1994); Kahn (1997); Altonji and Devereux (2000); Gottschalk (2005); Fehr and Goette (2005); and Dickens et al. (2007). A few studies such as Bihan, Montornès and Heckel (2012), Barattieri, Basu and Gottschalk (2014), Kurmann and Mcentarfer (2017) and Ehrlich and Montes (2017), which use highly disaggregated data, also investigate the interaction between the frequency of nominal wage adjustments and delayed wage adjustments over the business cycle.

In this paper, we expand the existing literature on staggered nominal wage adjustments and fill an important gap by providing a detailed empirical analysis of industry, firm, and worker-level channels that are likely to explain state dependence versus time dependence in nominal wage stickiness. Specifically, using a micro-detailed approach we aim to understand which particular characteristics of employee-employer relationships, contracts, firms and industry, induce nominal wages to remain rigid during economic downturns.

A recent study that is closely related to our research is Sigurdsson and Sigurdardottir (2016), whose analysis with administrative data from Iceland reveals the presence of time and state dependency components in the setting of nominal wages. The authors' study shows that in Iceland downward rigidities of nominal wages are present to a large extent, and that wages tend to contract in response to recessionary trends, which indicates the relevance of state-dependent wage setting. The Icelandic administrative data, however, to some extent restrict the conclusions reached by the authors on the deeper determinants of state-dependent salaries, since they can only contrast the behavior of nominal wages across industries, occupations and size of the firms. In this current study, we use administrative data from the Netherlands, which given its structure, allows us to make detailed comparisons between different employment relationships, contracts, occupations, firms and industry characteristics. The ability to make such comparisons also provides us with a framework to investigate the determinants of state dependence versus time dependence on wage determination.

Several theoretical foundations have been highlighted in the literature that could explain why firms may hesitate to cut wages during economic downturns. Campbell and Kamlani (1997) provides a review of the theoretical literature and conducts a firm-level survey to isolate the different theories of wage rigidity qualitatively. However, the absence of observational data in the analysis of Campbell and Kamlani (1997) limits the applicability of their conclusions. Some promising theories for understanding wage rigidity are contract theory, the theory of implicit contracts, theories of efficiency wages, the theory of fair wages and the theory of insider-outside information. The contracts approach to wage rigidities, as proposed by Fischer (1977) and Taylor (1980), suggests that long-term employee-firm agreements require that wages be fixed in advance, which prevents wage negotiations from taking place on a regular basis. Advocates of implicit contract theory, such as Azariadis (1975) and Stiglitz (1984), argue that workers' risk aversion would induce them to prefer stable wages during the business cycle to wages that increase during expansions and decline during recessions. Therefore, risk aversion would give incentives to firms and workers to come to an implicit understanding of keeping wages stable during the business cycle. The implicit theory of contracts would imply that, wherever wages are rigid, firms are expected to pay relatively lower wages by avoiding to compensate for risk premia.

Our empirical analysis uses Dutch data at the employee level that cover from 2006 to 2012 (84 months). The details of the data will be elaborated below. Our preliminary results show that the frequency of nominal wage adjustments in the Netherlands coincides with the aggregate wage rigidity documented recently for other European countries using high frequency data on wages such as for France (Bihan, Montornès and Heckel (2012)), Luxembourg (Lünnemann and Wintr (2009)) and Iceland (Sigurdsson and Sigurdardottir (2016)).

We divide the empirical analysis into two parts. In the first part we provide a description of the nominal wage stickiness of the Dutch economy. In this preliminary phase we find that nominal wages are downward rigid across a wide range of industrial clusters. We also document a clear seasonal pattern in the degree of rigidity. Likewise, we document significant heterogeneity in nominal wage rigidity across industries and occupations, as well as regarding the size of firms. As a unique contribution of our research, we find empirical evidence that the contractual terms of employees are an important determinant of the degree of nominal wage rigidity. Specifically, the number of hours worked, the duration of the contract and the status of the employment relationship turn out to be important sources of heterogeneity in the nominal wage rigidity among workers.

These findings not only help to understand the determinants of aggregate nominal wage rigidity, but are also increasingly relevant given the change in composition observed in the participation of different types of contract and employment policies during the period of analysis. Specifically, the change observed in the Dutch economy towards more flexible labor relations, in particular the growing participation of on-call workers, flexible contracts, and part-time contracts, which we also discussed.

Moreover, the duration analysis of a change in the contract wage confirms earlier findings in the literature regarding the shape of the hazard function. Accordingly, we find that the hazard has two spikes, one at 12 months and one at 24 months.

In the second part of our paper, using a formal econometric exercise, we study time-dependence and state-dependence in the determination of nominal wages in the Netherlands. We find that time- and state-dependency (this is represented by changes in macroeconomic variables, such as inflation and unemployment) determine the probability of observing both increases and nominal wage reductions. Time- and state-dependency affect the probability of observing changes in nominal wages for the pooled sample, that is, without disaggregation by type of contract, but also when considering the different types of contracts separately. In this last case, we find that the effect of time- and state-dependency is not homogeneous through the different contracts.

Thus, for example, we find that increases in nominal wages in contracts with flexible hours depend to a greater extent on the temporal dimension while not reacting to the evolution of accumulated unemployment. In similar lines, for tenured contracts, the probability of a wage increase does not depend on changes in accumulated inflation and only slightly responds to variations in accumulated unemployment. The results show a sharp contrast between full-time and part-time contracts. In the former, the response of the probability of observing a wage increase to changes in accumulated inflation is almost double compared to the latter.

The rest of this paper is organized as follows. Section 4.2 presents a summary of the theories of wage rigidity while Section 4.3 summarizes the institutional setting for wage determination in the Netherlands. Section 4.4 describes in detail the data we use. Sections 4.5 and 4.6 present our empirical results. Section 4.7 concludes.

4.2 Theories of Wage Rigidity: Time-Dependent vs. State-Dependent Wage Setting

There are two broad classes of theories that aim to describe the behavior of wage adjustments: time-dependent and state-dependent models of wage determination. According to time-dependent models of wage adjustments, the state of the economy does not play any role in determining the likelihood and the size of a wage change. Earlier examples of time-dependent wage setting include Fischer (1977) and Taylor (1980), who propose that wages remain constant for an exogenous and deterministic number of periods, such as a particular number of months or a year. Fisher-Taylor type of time-dependent wage setting can be motivated by the behavior of wages observed among unionized workers. Also, in this family of models, a feature pioneered in Calvo's famous 1983 article suggests a random duration in nominal adjustments.[1] Building upon this feature, many New-Keynesian macro models, such as Smets and Wouters (2003), assume that wages change at random with a probability to re-optimize wages that remains constant over time. Although Calvo type wage stickiness is hard to support with an empirically justifiable microfoundation, the tractability that it induces makes Calvo-stickness a desirable assumption to apply in New-Keynesian models.

Models with state-dependent wage setting build upon the theoretical argument that fixed costs to renegotiate employment contracts prevent frequent adjustments in wages. Assumptions proposed by Caplin and Spulber (1987) and Fehr and Goette (2005) argue that fixed cost of wage adjustments imply that the likelihood and the size of wage changes vary over time with the conditions of the macroeconomy, the industry and the firm.

In this paper we aim to disentangle the presence of time-vs-state dependent wage setting using a rich data-set for the case of the Netherlands.

4.3 Institutional Setting

The Netherlands is a small, open economy and part of the eurozone for the years of our study. With a population of 16.9 million inhabitants in 2015, it is more populous than the state of Illinois, but smaller than the state of New York.

[1]Although Calvo (1983) develops a model of sticky-prices, many papers in the literature implemented Calvo stickiness also for the case of wages.

Table 4.1: Composition of fixed-term contracts

	Percentage
On-call	31%
Temporary, perspective of indefinite	15%
Temp agency	14%
Temporary >=1 year	11%
Temporary <1 year	10%
Temporary contract, no contract hours	12%
Indefinite contract, no contract hours	7%

In 2015 there were about 8.29 million people in the labor force, with 6.9 million workers and 1.38 million self-employed. The three largest industries in terms of workers are health care (16%), trade (15%), and manufacturing (10%).

Important for our analysis is the distinction between workers with a contract of indefinite length (74% as of 2015) and a fixed-term contract (26%). As Table 4.1 shows, the group of fixed-term contracts is quite heterogeneous: 31% of the workers with a fixed-term contract are on-call; 19% have no hours defined, and 14% work for temporary work agencies (Dutch Labor Force Survey Statistics for 2015). Of the remaining workers with fixed-term contracts, 10% of the workers have a temporary contract for less than a year, and 11% have a temporary contract longer than a year.

Legally there are no limits on the length of time of the first fixed-term contract an employer offers, but there are regulations for the maximum number of successive contracts the employer can offer before a fixed-term contract alters into a contract of indefinite length (OECD EPL database, 2013). After three successive fixed-term contracts and/or a period of 36 months covered (including prolongations), the fourth (or next) contract is automatically of indefinite length. Exceptions to this rule are possible in collective bargaining agreements. In practice, the difference between temporary contracts and contracts of indefinite duration is the degree of employment protection. Termination of a labor contract by the employer involves either the courts or the public employment service (OECD EPL database, 2013), with an equal distribution of cases between the two. The courts are more expensive in terms of severance pay but are typically shorter and less administratively burdensome for the employer. Severance pay depends on the tenure of employment, gross wages and some discretionary factor applied by the courts. The average OECD score for job protection of workers with a regular contract is 2.04 in 2013 (on a scale from 0, no protection, to 6, maximum job protection). Workers with regular contracts in the Netherlands are better protected (score of 2.82) compared to the OECD. The opposite is true for workers with a temporary contract: the OECD average is 1.72, whereas the score for Dutch workers with a temporary contract is 0.94.

With respect to hours worked, the Dutch labor market can be characterized by a high degree of labor flexibility. In 2015 almost half of all workers worked less than the standard number of hours: 26.3% of the men and 75.1% of the women. The share of involuntary part-time work is very low: 8.6% of part-time workers work less than fulltime involuntarily (OECD, 2015). Overtime hours are measured in our data to the extent that hours are paid at a higher wage rate, e.g. weekend and night shifts in certain industries. Overtime premiums and overtime hours regulation are typically covered in collective bargaining agreements.

Trade union density, defined as the number of union members over the number of wage and salary earners, is with 17.8% comparable to the OECD average of 17.0% (OECD, 2013). For comparison with some of the mentioned studies, trade union density is lower in France (7.7%) and the United States (10.7%), and higher in Luxembourg (32.8%) and Iceland (82.4%). Union membership is low, but coverage of wage bargaining is relatively large. Four bargaining regimes can be distinguished (Hartog, Leuven and Teulings (2002)): company level bargaining, industry level bargaining, mandatory extension of an industry agreement, and no collective bargaining.

Figure 4.15 in Appendix 4.8 shows the behavior of GDP growth, CPI inflation and unemployment in the Netherlands in the period 2006-2012.

4.4 Data

One reason empirical research on wage rigidity is limited - especially to the end of identifying the models and theoretical channels that drive the degree of wage rigidity - is the lack of high-frequency microdata, which provide detailed information on contracts between employees and employers. In this respect, there are two fronts of the state of the art datasets that are required to conduct this research project. On the one hand, to capture potential rigidities in wage adjustments over the business cycle frequency, the data should be at a monthly (or at the least of quarterly) frequency. On the other hand, the details of employment contracts should provide enough information about the duration of the agreement and other features of the employee-employer relationship to allow for a thorough investigation of the sources of wage rigidity.

The analysis in this paper is based on anonymized non-public census-data from Statistics Netherlands (CBS) for the period of 2006-2012. In particular, the dataset allows us to use information on firms from the General Business Register (ABR), personal characteristics of individuals affiliated with municipal administration registers (GBA) and monthly quantitative and qualitative data regarding jobs and wages of employees in Dutch companies (POLISBUS).[2] Firms collect the monthly wage data and report it to the unemployment insurance agency. All legal workers are covered by unemployment insurance, and unemployment insurance is based on the number of years of work at all firms (including gaps), and the wages earned in the 12 months prior to unemployment, as well as hours worked. The fact that firms report the data minimizes the measurement error in wages and hours reported. Moreover, we observe in our data the universe of firms, both public and private.

In the first quarter of 2007, the census comprises around 980,000 firms with approximately 8,05 million workers among 480 industries (5-digit NACE), from which, due to computational constraints, we take a 5% random sample stratified by sector and firm size. The data includes monthly contract wages, variable compensation, payroll taxes and hours worked. At the level of the firm 5-digit industry code, collective labor agreement code (if any), and firm balance sheets and income statements can be linked to workers at incorporated firms. The observational unit is defined as the relationship between an employee and the employee's job at a firm (i.e., wage trajectory) which can be followed for up to seven years in our sample. The use of the wage trajectory as our observation unit means that the wage changes discussed in this paper are *within job* wage changes. As standard in the literature, our measurement unit is hourly wages, where wages are given by the contract wage.

Measuring the nominal rigidity in wages is challenging for two reasons: low frequency (annual) data and measurement error in wages, hours or both. The dataset we use in our research helps us with both issues. First, the employee-level dataset is at a monthly frequency giving us the opportunity to observe the exact month of a wage change *within a given wage trajectory*. We also observe the exact month of a new wage trajectory, as well as the month of a job exit and entry. Moreover, we can decompose total monthly compensation into the contract wage and variable compensation. These are important improvements on existing research. Most available microeconomic datasets on wages are at an

[2]Under certain conditions, these microdata are accessible for statistical and scientific research. For further information please contact Statistics Netherlands at microdata@cbs.nl.

annual frequency making the estimation of short-run wage rigidities quite imprecise. Only few studies provide evidence on wage rigidities at a quarterly frequency, such as Bihan, Montornès and Heckel (2012) for France, and Barattieri, Basu and Gottschalk (2014) for the United States; or at the monthly frequency: Lünnemann and Wintr (2009) for Luxembourg, and Sigurdsson and Sigurdardottir (2016) for Iceland. To the end of contractual details, our data differentiates between variable and base compensation of employees, provides information on hours worked, and the type of contracts (fixed-term versus permanent). The second challenge is measurement error. Gottschalk (2005) finds that measurement error in surveys can be substantial, due to imperfect recall or unwillingness to report hours worked or wages received (or both).

Our research isolates the effects of explicit contractual terms on estimated wage rigidities from that of factors due to firm, industry and macroeconomic characteristics. Moreover, we observe all employees at each firm, which allows us to identify each firm-worker pair in the data uniquely. An additional novel feature of our data is that we observe start and end of unemployment spells and can precisely infer wage changes of job-finders.

Our empirical methodology to estimate wage rigidity follows the recent literature (e.g., Gottschalk (2005); Bihan, Montornès and Heckel (2012); Barattieri, Basu and Gottschalk (2014)) and Sigurdsson and Sigurdardottir (2016).

Data Treatment. Even though we are dealing with high-quality administrative data, some observations should be excluded because it is likely that they contain measurement errors or are the result of misreporting. Specifically, we leave out any observations with nonsense values (e.g. negative nominal wages or number hours worked) and to trim possible outliers, we drop the first and/or the last percentile in most of the variables.

The data cleaning process, however, does not entirely eliminate the presence of measurement error, or misreporting, which may obscure our estimation of the level of wage rigidity. Specifically, we could potentially find spurious changes in wages that are the product of misreporting or due to rounding. In order to differentiate ?actual? wage changes from the spurious ones, and reduce the bias generated by the latter, we implement an identification strategy that is standard in the literature. In general terms, the identification strategy assumes that a step function can describe wage changes. That is, we assume (as intuition dictates) that individual wages stay constant for some unknown number of months and then, when they change, they change in a discrete manner. One way to implement this identification strategy is using a structural break test. However, this econometric approach used by Gottschalk (2005) is computationally expensive and becomes infeasible when the number of wage trajectories is big, as in our case.[3] Instead, we implement the identification strategy using a heuristic approach which can be summarized as follows:[4]

1. We eliminate the last observation of a wage trajectory if this includes a wage change. This allows us to take into account any possible payment received by the employee at the end of the labor relationship, such as severance payments. Symmetrically, we eliminate the first observation of a wage trajectory if it is followed by an immediate change in wage as well. This way we take into account any possible "extra" payments that wage earner receives in the first month of the employment relationship, e.g. sign-on bonuses.

2. We drop wage trajectories that last for less than 3-months. The idea behind this is to avoid the possible bias generated by very short and potentially volatile wage trajectories.

3. We eliminate wage trajectories where the number of wage changes is greater than 80% of the total possible number of changes (e.g., a wage trajectory of 12 months with ten wage changes is dropped from our analysis). This is in line with our overall identification strategy: wages stay constant for some unknown period.

4. We correct wage trajectories that contain V-shape or inverted V-shape wage changes, i.e. a wage reduction followed immediately by an increase (or vice versa). This kind of sharp wage reversals are potentially due to misreporting or due to rounding error. In our analysis, we take such sharp wage-reversals as a "no-change" in wage.

5. Finally, we correct wage trajectories that contain wage reversals in a time span of three months, i.e. a wage change that is reverted after two or three months leaving the wage exactly as before the change. We consider those wage-reversals as a "no-change" in wage.[5]

Figure 4.1 depicts the implementation of the above algorithm for a fictional individual over a 24-month wage trajectory.[6]

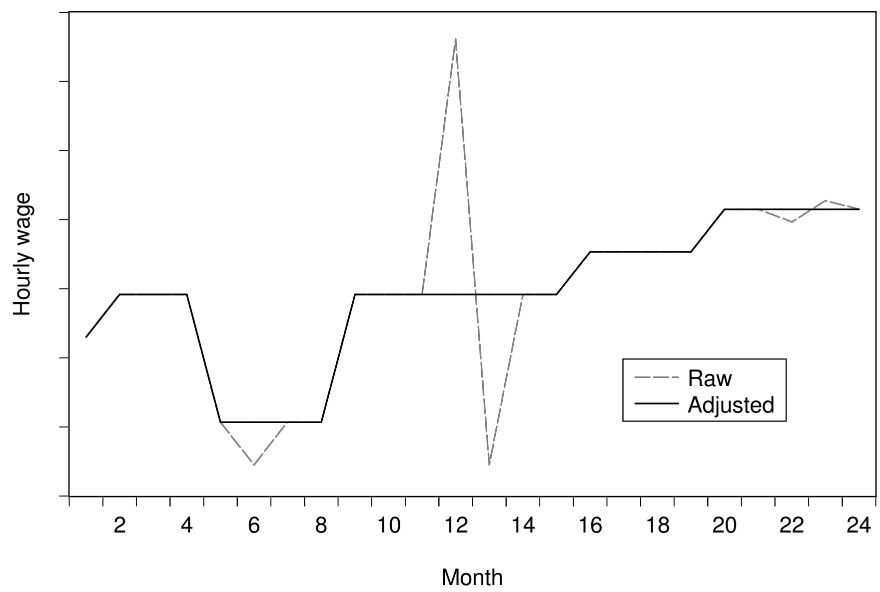
[3]See Barattieri, Basu and Gottschalk (2014) for an application.

[4]A similar approach is used in Sigurdsson and Sigurdardottir (2016) and Lünnemann and Wintr (2009).

[5]Table 4.16 in Appendix 4.8 shows the number of observations lost in each step of the cleaning process.

[6]The wage trajectory in this figure does not correspond to the wage trajectory of any individual in our sample nor in the population. The numbers were fabricated for illustrative purposes.

Figure 4.1: Raw and adjusted wage trajectory



Note: The wage trajectory in this figure does not correspond to the wage trajectory of any individual in our sample nor in the population. The numbers were fabricated for illustrative purposes.

4.5 Wage Rigidity: Descriptive Analysis

In this section we conduct a duration analysis and a multinomial logit estimation to document the patterns of employee-level wage adjustments in the Netherlands. We split our results in two. At first, we present a set of findings, some of which have also been highlighted in the previous literature for other European countries and the US. We then show and discuss another set of findings that are novel for the literature.

The baseline results - that we present in tables 4.2-4.7 and figures 4.4-4.9 - reveal the presence of rigid wages, and in particular downward wage rigidities throughout sectors, firm-size groups and employment types. This means when we compare wage "decreases" against "increases", contractions in wages are significantly less common than rising wages. These results are in line with those found in the literature as we will delineate below.

Table 4.2 shows that in the aggregate we capture a frequency of "no-change in wages" of 84.9%. This degree of wage rigidity is comparable to the findings of Sigurdsson and Sigurdardottir (2016), who document 87% probability of "no change in wages" for the case of Iceland, and Lünnemann and Wintr (2009), who document 85.7%- 93% probability of "no change in wages" for the case of Lux-

Table 4.2: Wage rigidity

	Frequency			Average size	
	Decrease	No change	Increase	Decrease	Increase
Aggregate	3.2 [3.0; 3.3]	84.9 [84.6; 85.2]	11.9 [11.7; 12.1]	-8.9	4.8
Employment policy					
Full-time	2.9 [2.6; 3.2]	85.5 [84.8; 86.1]	11.6 [11.1; 12.1]	-9.5	4.2
Part-time	3.5 [3.2; 3.7]	84.3 [83.9; 84.8]	12.2 [11.8; 12.6]	-8.7	5.4
Employment relationship					
Fixed	3.0 [2.8; 3.3]	85.2 [84.7; 85.7]	11.8 [11.4; 12.2]	-9.0	4.8
Flexible	8.1 [7.5; 8.7]	76.1 [75.5; 76.7]	15.8 [15.4; 16.3]	-9.5	5.8
Type of contract					
Tenured	4.2 [3.8; 4.7]	82.7 [81.9; 83.4]	13.1 [12.7; 13.5]	-11.5	7.0
Untenured	2.9 [2.7; 3.2]	85.4 [84.8; 85.9]	11.7 [11.3; 12.2]	-7.9	4.1
Not applicable	3.8 [3.7; 3.9]	91.4 [91.2; 91.6]	4.8 [4.7; 4.9]	-15.4	13.3
Type of relationship					
Marriage	3.0 [2.7; 3.2]	85.8 [85.2; 86.3]	11.3 [10.8; 11.7]	-8.5	4.2
Partnership	3.0 [2.7; 3.3]	85.1 [84.5; 85.6]	11.9 [11.4; 12.4]	-8.5	4.1
Single	3.4 [3.1; 3.7]	84.0 [83.4; 84.5]	12.6 [12.2; 13.0]	-9.4	5.5
Gender					
Male	3.2 [2.9; 3.6]	85.3 [84.6; 85.9]	11.5 [11.0; 12.0]	-8.6	4.7
Female	3.1 [2.9; 3.4]	84.6 [84.1; 85.1]	12.2 [11.9; 12.6]	-9.2	4.9

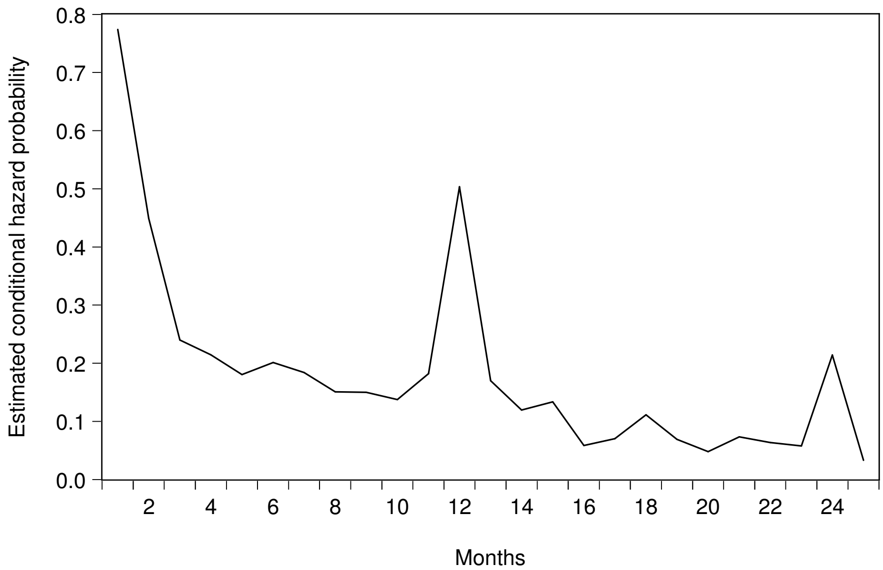
Marginal effects from multinomial logit models. All the numbers are percentages, and rows sum up to a 100%. Confidence intervals in brackets. The last two columns represents the percentage change in nominal wage, conditional on a wage decrease or increase. The total number of observations is 13,174,294.

emburg. Both of these studies - like in our approach - use monthly data. Using quarterly data Bihan, Montornès and Heckel (2012) find a wage rigidity of 62% in France and Barattieri, Basu and Gottschalk (2014) uncover a wage rigidity of 78.4%-83.7% in the US. The quarterly equivalent of our wage rigidity is 62.1% of no-change, which coincides with the degree of rigidity documented in France by Bihan, Montornès and Heckel (2012).

Figure 4.2 shows the estimated conditional hazard probability of a wage change based on the raw data. This figure indicates that wages are more likely to change every 12 months, and to a lesser extent if the wage remains unchanged for two years. More importantly, the high probability of observing a wage change every period depicted in Figure 4.2 reveals the presence of significant measurement errors in the raw data.

Figure 4.3 presents the hazard function of a wage change based on the data obtained after the cleaning procedure explained in detail in Section 4.4. The highest probability of a wage change is observed after 12 months: an employee

Figure 4.2: Hazard function of wage changes - Raw data



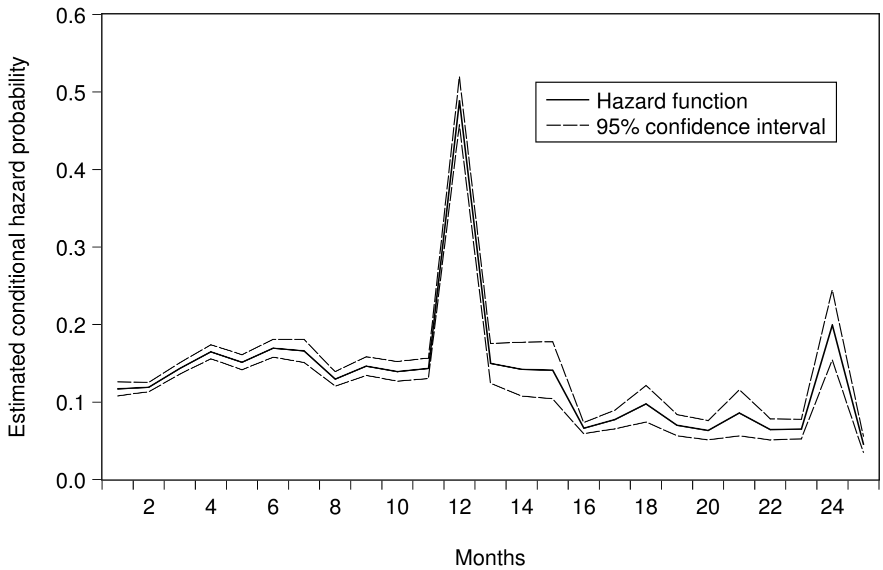
Source: Own calculations.

who had an unchanged wage for 11 months has about a 50% chance of observing a change in his wage in the 12th month.

Similarly, if the wage remained unchanged for 23 months, the worker has a probability close to 20% of observing a wage change in month 24. A similar hazard function - with peaks in 12th and 24th months - was also documented by Gottschalk (2005) and Barattieri, Basu and Gottschalk (2014) for the case of the United States.

Moreover, Figure 4.4 and Table 4.3 reveal a clear seasonality (synchronization) in wage changes. We find that wages are more likely to rise in January and July. Sigurdsson and Sigurdardottir (2016) found a similar pattern in Iceland but the peaks in their work are documented to be in January and June. Similarly, using the administrative data from Luxemburg Lünnemann and Wintr (2009) uncovered a peak in January. Bihan, Montornès and Heckel (2012) also showed a synchronization in wage changes for the case of France. Finally, for the US Barattieri, Basu and Gottschalk (2014) showed weak evidence of synchronization. Additionally, our data also points out that there is evidence of staggered wages at

Figure 4.3: Hazard function of wage changes - Adjusted data



Source: Own calculations.

the aggregate level. Figure 4.4 and Table 4.3 show that most of the wage changes are distributed over the course of the year.[7]

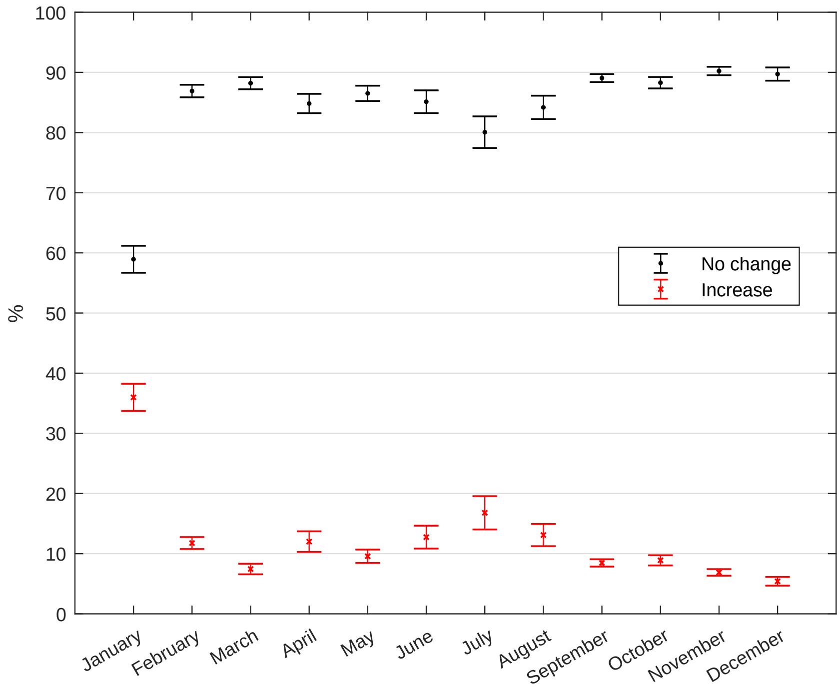
Figure 4.5 and Table 4.4 (in Appendix 4.8) show that wages in the Netherlands have become more rigid after the financial crisis. Sigurdsson and Sigurdardottir (2016) found a similar pattern regarding the increase of wage rigidity after the crisis for the case of Iceland. However, it is important to note that the "economic recovery" had not been observed yet in the data that they use, because the last period for the analysis is 2010 in Sigurdsson and Sigurdardottir (2016).[8]

The results we obtain to the end of variations in marital status and gender of the employee and their implications for wage rigidities are in line with the findings of the previous literature as well. With respect to the marital status the rigidities are comparable between married and non-married, while married workers tend to exhibit rigidities to a larger extent (as also evidenced in Lünnemann and Wintr (2009)). Similarly, results are very close between male and female employees, but male workers appear to have more rigid wage profiles compared to female (also as in Lünnemann and Wintr (2009)).

[7]For France, Bihan, Montornès and Heckel (2012) found a stronger evidence of staggering (the probability of a wage increase is greater than 20% in every quarter).

[8]However, it is too early to talk about a sustained recovery since the Netherlands registered a negative GDP growth in the last year of our analysis.

Figure 4.4: Months



Source: Own calculations.

Table 4.3: Month

	Frequency			Average size	
	Decrease	**No change**	**Increase**	**Decrease**	**Increase**
January	5.1 [4.5; 5.7]	58.9 [56.7; 61.2]	36.0 [33.7; 38.2]	-10.0	4.8
February	1.3 [1.2; 1.5]	86.9 [85.9; 87.9]	11.8 [10.8; 12.8]	-10.9	6.7
March	4.3 [3.8; 4.9]	88.2 [87.2; 89.2]	7.4 [6.6; 8.3]	-8.0	6.0
April	3.2 [2.8; 3.6]	84.8 [83.2; 86.4]	12.0 [10.3; 13.7]	-9.1	4.4
May	3.9 [3.5; 4.4]	86.5 [85.2; 87.8]	9.6 [8.5; 10.7]	-7.9	4.2
June	2.1 [1.9; 2.3]	85.1 [83.2; 87.0]	12.7 [10.8; 14.7]	-10.7	4.0
July	3.1 [2.9; 3.4]	80.1 [77.4; 82.7]	16.8 [14.0; 19.6]	-10.8	3.3
August	2.7 [2.5; 3.0]	84.2 [82.2; 86.1]	13.1 [11.2; 14.9]	-8.6	4.3
September	2.5 [2.3; 2.7]	89.1 [88.4; 89.7]	8.5 [7.8; 9.1]	-8.9	6.5
October	2.8 [2.6; 3.0]	88.3 [87.3; 89.2]	8.9 [8.0; 9.7]	-8.2	4.9
November	2.9 [2.6; 3.1]	90.2 [89.5; 90.9]	6.9 [6.3; 7.4]	-8.6	5.9
December	4.9 [4.3; 5.5]	89.7 [88.6; 90.8]	5.4 [4.7; 6.1]	-8.6	5.2

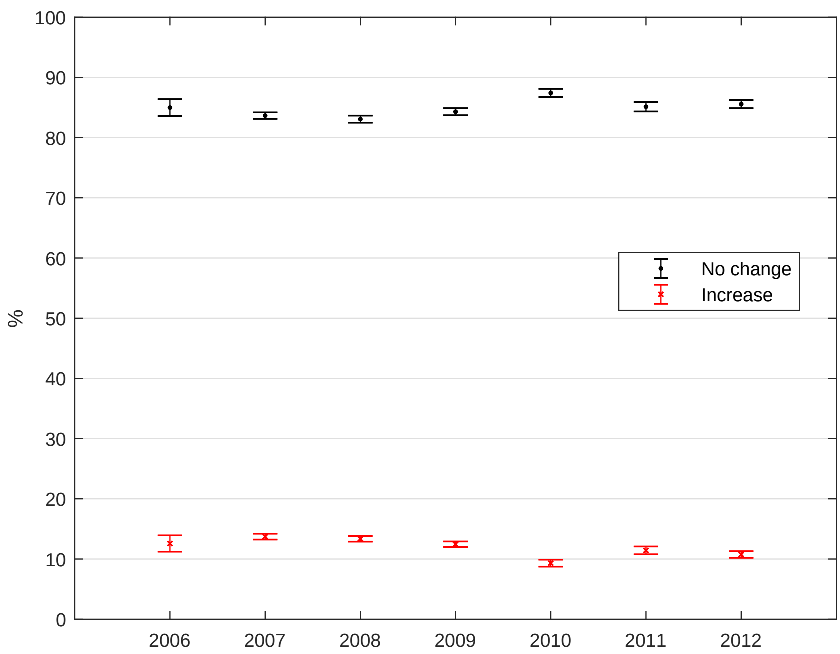
Marginal effects from multinomial logit models. All the numbers are percentages, and rows sum up to a 100%. Confidence intervals in brackets. The last two columns represents the percentage change in nominal wage, conditional on a wage decrease or increase. The total number of observations is 13,174,294.

Table 4.4: Year

	Frequency			Average size	
	Decrease	**No change**	**Increase**	**Decrease**	**Increase**
2006	2.4 [2.2; 2.7]	85.0 [83.6; 86.4]	12.6 [11.2; 13.9]	-10.6	5.0
2007	2.6 [2.4; 2.9]	83.7 [83.1; 84.2]	13.7 [13.2; 14.2]	-11.1	4.8
2008	3.6 [3.2; 3.9]	83.1 [82.5; 83.7]	13.4 [12.9; 13.8]	-9.1	5.5
2009	3.2 [2.9; 3.5]	84.3 [83.7; 84.9]	12.5 [12.0; 12.9]	-8.6	4.9
2010	3.3 [3.0; 3.6]	87.4 [86.7; 88.1]	9.3 [8.7; 9.9]	-9.1	5.2
2011	3.4 [3.1; 3.8]	85.1 [84.3; 85.9]	11.4 [10.8; 12.1]	-7.9	4.3
2012	3.7 [3.3; 4.1]	85.6 [84.9; 86.2]	10.8 [10.2; 11.3]	-8.0	4.2

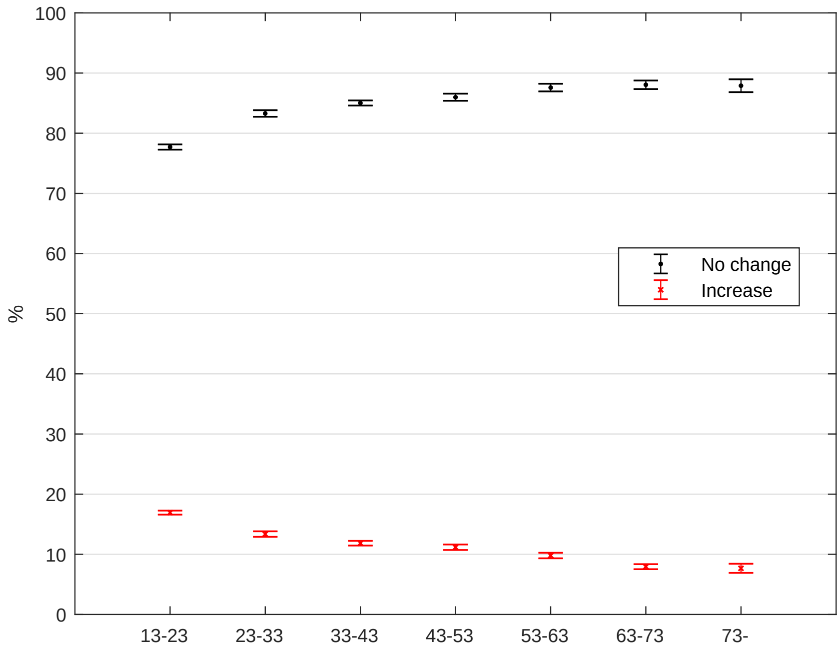
Marginal effects from multinomial logit models. All the numbers are percentages, and rows sum up to a 100%. Confidence intervals in brackets. The last two columns represents the percentage change in nominal wage, conditional on a wage decrease or increase. The total number of observations is 13,174,294.

Figure 4.5: Years



Source: Own calculations.

Figure 4.6: Age



Source: Own calculations.

As a novel piece of evidence Figure 4.6 and Table 4.5 uncover a clear positive correlation between age and wage rigidity.[9] For instance, the probability of a no-change in wages grows monotonically with the age of the employee until they reach 73 years (for employees over 73 years of age, the probability of a non-change decreases slightly). Therefore, while for employees between 63 and 73 years the likelihood of a no-change in wages is 88.1%, this likelihood is 77.7% for employees under 23 years of age. We observe a monotonic negative relationship between the age of the employee and the probability of a wage increase. As Table 4.5 shows young workers are twice as likely to experience a wage increase compared to their older counterparts. The negative link between the age of the employee and the likelihood of a wage reduction shows less variance than for the cases of no-change and wage increases.

The implication of the estimated correlation between wage rigidity and workers' age gains additional relevance once we observe the behavior of the age groups during the observation period. Figure 4.7 shows this evolution between 2006 and 2012. We can see that, in general, the age groups with less rigidity

[9] Lünnemann and Wintr (2009) discuss the association between age and wage rigidity as well, but in their case age cannot be separated from marital status.

Table 4.5: Age

	Frequency			Average size	
	Decrease	**No change**	**Increase**	**Decrease**	**Increase**
13-23	5.4 [5.2; 5.6]	77.7 [77.3; 78.1]	16.9 [16.6; 17.3]	-10.0	9.1
23-33	3.4 [3.1; 3.6]	83.3 [82.7; 83.8]	13.4 [12.9; 13.8]	-10.0	5.2
33-43	3.1 [2.9; 3.4]	85.0 [84.6; 85.4]	11.8 [11.5; 12.2]	-8.8	4.4
43-53	2.8 [2.6; 3.1]	86.0 [85.4; 86.6]	11.2 [10.7; 11.6]	-7.7	3.8
53-63	2.6 [2.3; 2.9]	87.6 [86.9; 88.2]	9.8 [9.3; 10.3]	-8.1	3.8
63-73	4.0 [3.6; 4.4]	88.1 [87.3; 88.8]	7.9 [7.5; 8.4]	-11.3	5.7
73-	4.4 [3.9; 5.0]	87.9 [86.8; 89.0]	7.7 [6.9; 8.4]	-11.8	7.5

Marginal effects from multinomial logit models. All the numbers are percentages, and rows sum up to a 100%. Confidence intervals in brackets. The last two columns represents the percentage change in nominal wage, conditional on a wage decrease or increase. The total number of observations is 13,174,294.

in wages, ages between 23 and 53 years, have decreased their participation in the working population. In contrast, employees over 53 have shown a steady increase in their share.

Finally, we also document the heterogeneity of wage rigidities with respect to firms' size and industry classifications. First, Figure 4.8 and Table 4.6 illustrate that wages become more flexible with the size of the company, which was also highlighted in the past literature.[10] Also, as documented in the past literature, we show that the probability of observing a wage increase is positively related to firm size.[11] We also find a negative relationship between firm size and the probability of a wage-contraction - as in Bihan, Montornès and Heckel (2012), which differs from the findings of Sigurdsson and Sigurdardottir (2016) and Lünnemann and Wintr (2009), who show that the probability of observing a wage decrease is essentially independent of firm size. Second, sectoral comparisons reveal that for workers at municipalities, schools and subsidized sectors wages are more downward rigid compared to the private sector, as illustrated in Table 4.7 (Figure 4.9). Further decomposition of the sectors in industries shows that, for instance, wages in the Telecommunication industry are the least-rigid whereas the wages of the Banking industry are most rigid - with a substantial amount of heterogeneity in the rigidity of wages across the spectrum of industries.[12]

Novel evidence. Employment contract details in our administrative data provide us with a novel source of variation at the employee level and allows to ex-

[10] Sigurdsson and Sigurdardottir (2016) and Lünnemann and Wintr (2009) find a similar empirical pattern, while Bihan, Montornès and Heckel (2012) find an inverted U-shaped - with more wage rigidity for the case of mid-size firms.

[11] The same pattern is observed by Sigurdsson and Sigurdardottir (2016), Lünnemann and Wintr (2009) and Bihan, Montornès and Heckel (2012)

[12] Table 4.17 in Appendix 4.8 shows a sectoral classification at a higher level of aggregation.

Figure 4.7: Participation of age groups

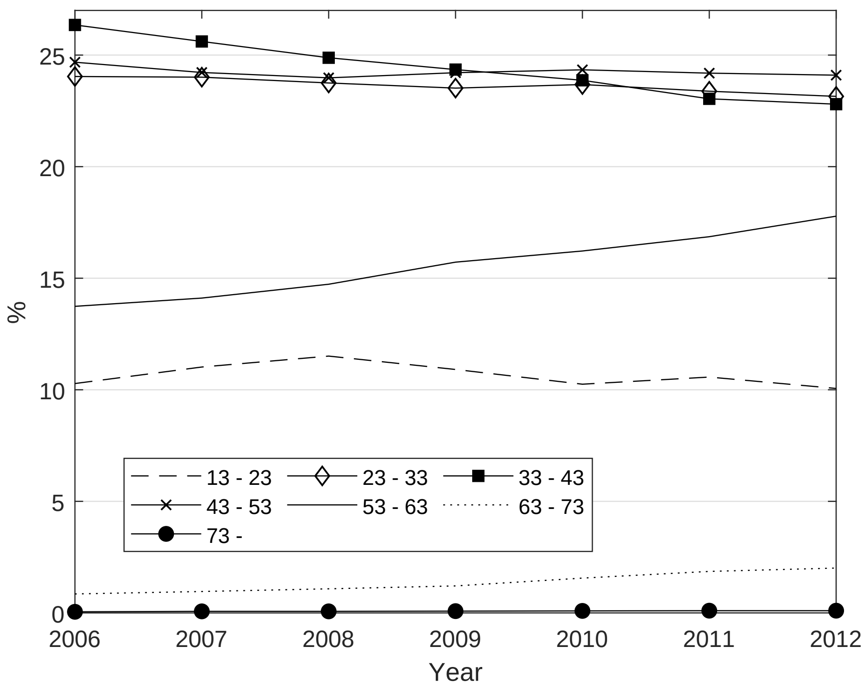
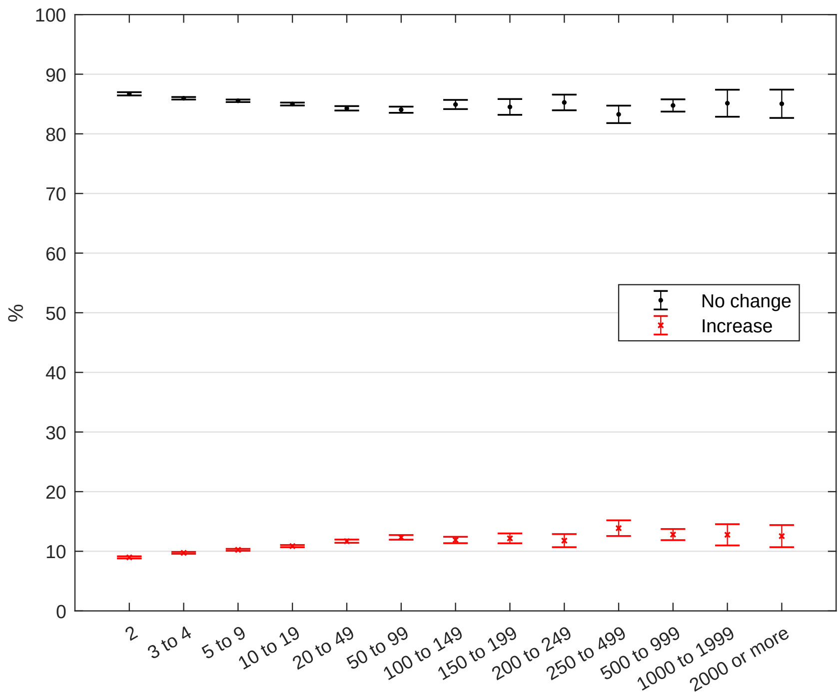
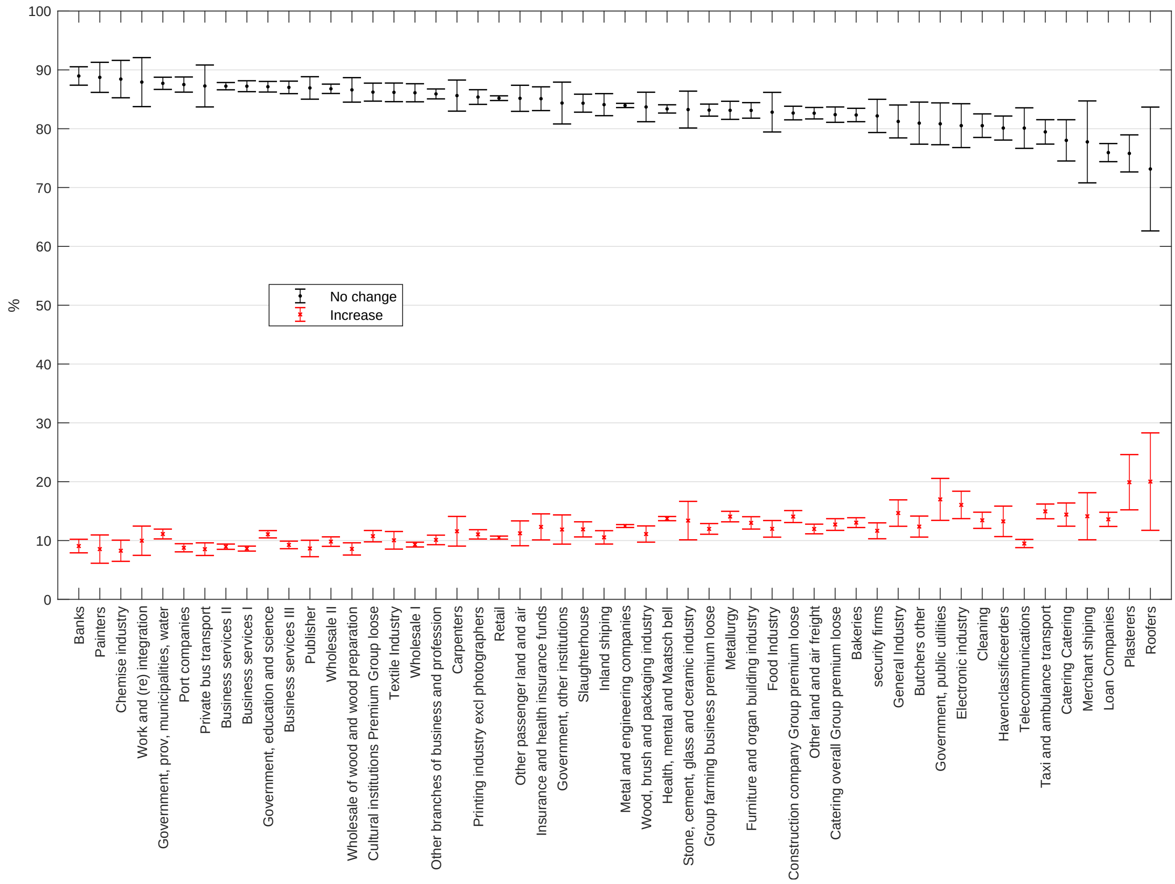


Figure 4.8: Business size (number of employees)



Source: Own calculations.

Figure 4.9: Sector



Source: Own calculations.

Table 4.6: Business size (number of employees)

	Frequency			Average size	
	Decrease	**No change**	**Increase**	**Decrease**	**Increase**
2	4.3 [4.1; 4.5]	86.7 [86.4; 87.0]	9.0 [8.8; 9.2]	-9.1	7.9
3 to 4	4.3 [4.2; 4.4]	86.0 [85.8; 86.2]	9.7 [9.6; 9.9]	-9.0	7.3
5 to 9	4.2 [4.1; 4.3]	85.5 [85.3; 85.8]	10.2 [10.1; 10.4]	-8.5	6.5
10 to 19	4.1 [4.0; 4.3]	85.0 [84.8; 85.2]	10.9 [10.7; 11.0]	-8.7	6.0
20 to 49	4.0 [3.8; 4.2]	84.3 [83.9; 84.7]	11.7 [11.4; 12.0]	-9.5	5.5
50 to 99	3.6 [3.4; 3.9]	84.0 [83.5; 84.6]	12.3 [11.9; 12.7]	-10.8	5.1
100 to 149	3.2 [2.8; 3.6]	84.9 [84.1; 85.7]	11.9 [11.4; 12.4]	-10.3	5.1
150 to 199	3.3 [2.6; 4.1]	84.5 [83.2; 85.8]	12.2 [11.3; 13.0]	-9.0	4.7
200 to 249	3.0 [2.3; 3.6]	85.3 [84.0; 86.6]	11.8 [10.7; 12.9]	-8.7	4.4
250 to 499	2.9 [2.4; 3.3]	83.3 [81.8; 84.7]	13.9 [12.6; 15.2]	-7.8	3.8
500 to 999	2.4 [2.1; 2.8]	84.8 [83.7; 85.8]	12.8 [11.9; 13.7]	-6.7	3.5
1000 to 1999	2.1 [1.5; 2.7]	85.1 [82.9; 87.4]	12.8 [11.0; 14.5]	-12.3	4.7
2000 or more	2.4 [1.4; 3.5]	85.0 [82.7; 87.4]	12.5 [10.7; 14.4]	-7.4	3.5

Marginal effects from multinomial logit models. All the numbers are percentages, and rows sum up to a 100%. Confidence intervals in brackets. The last two columns represents the percentage change in nominal wage, conditional on a wage decrease or increase. The total number of observations is 13,174,294.

plore a set of empirical regularities, which the previous literature did not concentrate on. As we highlight in Table 4.2 we observe that employees with a flexible hours employment relationship have substantially lower degrees of wage rigidity - when it comes to both downward and upward adjustments in wages - compared to employees with fixed hours employment relationships.[13] The frequency of no change is 76.1% for the case of flexible hours contracts, while it is 85.2% for fixed hours contracts. Note that, in the Netherlands, the participation of employees with flexible contracts has increased considerably during the period of analysis (Figure 4.10). On the contrary, the participation of fixed contracts, although still a majority, has shown a constant decrease.

Although not as striking, our data also captures a difference in the degree of rigidity of wages when tenured and untenured contracts are compared against each other. Even small differences in the level of wage rigidity between these contracts can have important implications given how the participation of tenured and untenured contracts has evolved between 2006 and 2012. Figure 4.11 shows that the percentage of tenured contracts was relatively low in 2006, but it increased significantly in a period as short as six years (an increase of around ten percentage points). We observe the opposite behavior, but with the same magnitude, for untenured contracts.

[13] Flexible employment relationships include temporary workers and on-call. Fixed relationships correspond to directors, interns, SWS-er and rest. tables 4.14 and 4.15 in Appendix 4.8 shows the distribution of the different type of contracts in our sample.

Table 4.7: Sector

	Frequency			Average size	
	Decrease	**No change**	**Increase**	**Decrease**	**Increase**
Banks	2.0 [1.2; 2.8]	89.0 [87.4; 90.5]	9.1 [7.9; 10.2]	-13.2	6.5
Painters	2.7 [2.1; 3.3]	88.7 [86.2; 91.3]	8.5 [6.1; 10.9]	-9.6	7.5
Chemise industry	3.3 [1.5; 5.1]	88.4 [85.3; 91.6]	8.3 [6.5; 10.1]	-6.2	4.6
Work and (re) integration	2.1 [-0.1; 4.3]	87.9 [83.8; 92.1]	10.0 [7.5; 12.5]	-8.9	3.4
Government, prov, municipalities, water	1.2 [0.8; 1.5]	87.7 [86.7; 88.8]	11.1 [10.3; 11.9]	-4.4	2.4
Port companies	3.7 [3.0; 4.5]	87.5 [86.2; 88.8]	8.8 [8.1; 9.5]	-7.7	6.1
Private bus transport	4.2 [0.6; 7.8]	87.3 [83.7; 90.8]	8.5 [7.5; 9.6]	-11.2	6.9
Business services II	3.8 [3.5; 4.1]	87.2 [86.6; 87.9]	9.0 [8.5; 9.4]	-9.1	6.8
Business services I	4.1 [3.3; 5.0]	87.2 [86.3; 88.2]	8.6 [8.2; 9.0]	-9.0	7.0
Government, education and science	1.8 [1.5; 2.1]	87.1 [86.2; 88.0]	11.1 [10.4; 11.7]	-12.8	5.4
Business services III	3.7 [3.2; 4.3]	87.0 [86.0; 88.1]	9.3 [8.6; 9.9]	-9.4	6.5
Publisher	4.4 [3.3; 5.5]	86.9 [85.0; 88.8]	8.6 [7.2; 10.0]	-10.3	8.9
Wholesale II	3.4 [3.1; 3.7]	86.8 [86.0; 87.6]	9.8 [9.0; 10.6]	-8.5	5.3
Wholesale of wood and wood preparation	4.8 [3.4; 6.3]	86.6 [84.5; 88.7]	8.6 [7.5; 9.6]	-8.0	6.6
Cultural institutions Premium Group loose	3.0 [2.3; 3.8]	86.2 [84.7; 87.7]	10.7 [9.8; 11.7]	-7.3	5.2
Textile Industry	3.8 [3.1; 4.5]	86.2 [84.6; 87.8]	10.0 [8.5; 11.5]	-9.7	7.1
Wholesale I	4.6 [3.0; 6.2]	86.1 [84.6; 87.6]	9.3 [8.9; 9.7]	-8.0	6.1
Other branches of business and profession	4.0 [3.4; 4.5]	85.9 [85.1; 86.8]	10.1 [9.3; 10.9]	-8.2	6.2
Carpenters	2.8 [1.9; 3.7]	85.6 [83.0; 88.3]	11.6 [9.1; 14.1]	-8.3	4.8
Printing industry excl photographers	3.6 [2.9; 4.2]	85.4 [84.1; 86.6]	11.0 [10.3; 11.8]	-12.3	5.3
Retail	4.3 [4.1; 4.5]	85.2 [84.8; 85.6]	10.5 [10.2; 10.8]	-9.0	6.8
Other passenger land and air	3.6 [2.3; 4.9]	85.2 [82.9; 87.4]	11.2 [9.1; 13.3]	-11.3	6.4
Insurance and health insurance funds	2.6 [1.3; 3.9]	85.1 [83.1; 87.1]	12.3 [10.1; 14.5]	-11.5	4.8
Government. other institutions	3.8 [2.4; 5.2]	84.4 [80.8; 87.9]	11.9 [9.4; 14.4]	-5.9	3.4
Slaughterhouse	3.8 [3.2; 4.3]	84.3 [82.8; 85.9]	11.9 [10.6; 13.2]	-8.4	6.8
Inland shiping	5.4 [4.4; 6.3]	84.1 [82.2; 86.0]	10.5 [9.4; 11.7]	-8.8	9.9
Metal and engineering companies	3.6 [3.3; 3.8]	84.0 [83.6; 84.3]	12.5 [12.2; 12.7]	-8.9	5.5
Wood, brush and packaging industry	5.2 [3.7; 6.7]	83.7 [81.2; 86.2]	11.1 [9.7; 12.5]	-8.1	6.0
Health, mental and Maatsch bell	2.9 [2.4; 3.4]	83.4 [82.7; 84.1]	13.7 [13.4; 14.1]	-8.8	4.3
Stone, cement, glass and ceramic industry	3.4 [2.5; 4.3]	83.3 [80.1; 86.4]	13.4 [10.1; 16.7]	-7.1	4.0
Group farming business premium loose	4.9 [4.3; 5.4]	83.2 [82.1; 84.2]	12.0 [11.1; 12.9]	-6.8	5.8
Metallurgy	2.8 [2.0; 3.6]	83.1 [81.6; 84.7]	14.1 [13.2; 15.0]	-9.9	3.6
Furniture and organ building industry	3.9 [3.0; 4.8]	83.1 [81.8; 84.4]	13.0 [11.9; 14.0]	-9.6	4.5
Food Industry	5.2 [3.0; 7.4]	82.8 [79.4; 86.2]	12.0 [10.6; 13.4]	-18.2	8.1
Construction company Group premium loose	3.3 [2.6; 3.9]	82.7 [81.5; 83.8]	14.1 [13.1; 15.1]	-13.1	4.0
Other land and air freight	5.4 [4.7; 6.1]	82.6 [81.7; 83.6]	12.0 [11.1; 12.8]	-7.9	5.7
Catering overall Group premium loose	4.9 [4.3; 5.5]	82.4 [81.1; 83.7]	12.7 [11.7; 13.7]	-7.3	6.6
Bakeries	4.6 [4.1; 5.2]	82.3 [81.2; 83.5]	13.0 [12.2; 13.9]	-8.3	6.2
security firms	6.2 [3.5; 8.9]	82.2 [79.4; 85.0]	11.7 [10.3; 13.0]	-9.5	6.1
General Industry	4.1 [3.3; 4.9]	81.2 [78.4; 84.0]	14.7 [12.4; 16.9]	-6.3	3.4
Butchers other	6.7 [4.4; 9.0]	80.9 [77.4; 84.5]	12.4 [10.6; 14.2]	-8.0	5.9
Government, public utilities	2.2 [1.9; 2.5]	80.8 [77.3; 84.4]	17.0 [13.4; 20.6]	-5.5	2.1
Electronic industry	3.4 [1.5; 5.3]	80.5 [76.8; 84.2]	16.1 [13.7; 18.4]	-7.3	4.6
Cleaning	6.0 [5.2; 6.9]	80.5 [78.5; 82.5]	13.4 [12.1; 14.8]	-8.1	4.6
Havenclassificeerders	6.6 [5.6; 7.7]	80.1 [78.1; 82.2]	13.3 [10.7; 15.8]	-4.2	6.8
Telecommunications	10.4 [7.3; 13.5]	80.1 [76.7; 83.5]	9.5 [8.8; 10.2]	-6.5	6.3
Taxi and ambulance transport	5.6 [4.5; 6.7]	79.5 [77.4; 81.5]	15.0 [13.7; 16.2]	-6.3	4.2
Catering Catering	7.6 [6.0; 9.2]	78.0 [74.5; 81.5]	14.4 [12.4; 16.4]	-31.9	16.7
Merchant shiping	8.1 [3.8; 12.4]	77.8 [70.8; 84.7]	14.1 [10.1; 18.1]	-29.5	22.4
Loan Companies	10.5 [9.6; 11.3]	75.9 [74.4; 77.5]	13.6 [12.4; 14.8]	-18.7	6.6
Plasterers	4.3 [1.5; 7.1]	75.8 [72.7; 78.9]	19.9 [15.2; 24.6]	-10.5	4.2
Roofers	6.8 [4.3; 9.4]	73.2 [62.6; 83.7]	20.0 [11.7; 28.3]	-13.2	9.3

Marginal effects from multinomial logit models. All the numbers are percentages, and rows sum up to a 100%. Confidence intervals in brackets. The last two columns represents the percentage change in nominal wage, conditional on a wage decrease or increase. The total number of observations is 13,174,294.

Figure 4.10: Participation of flexible and fixed contracts

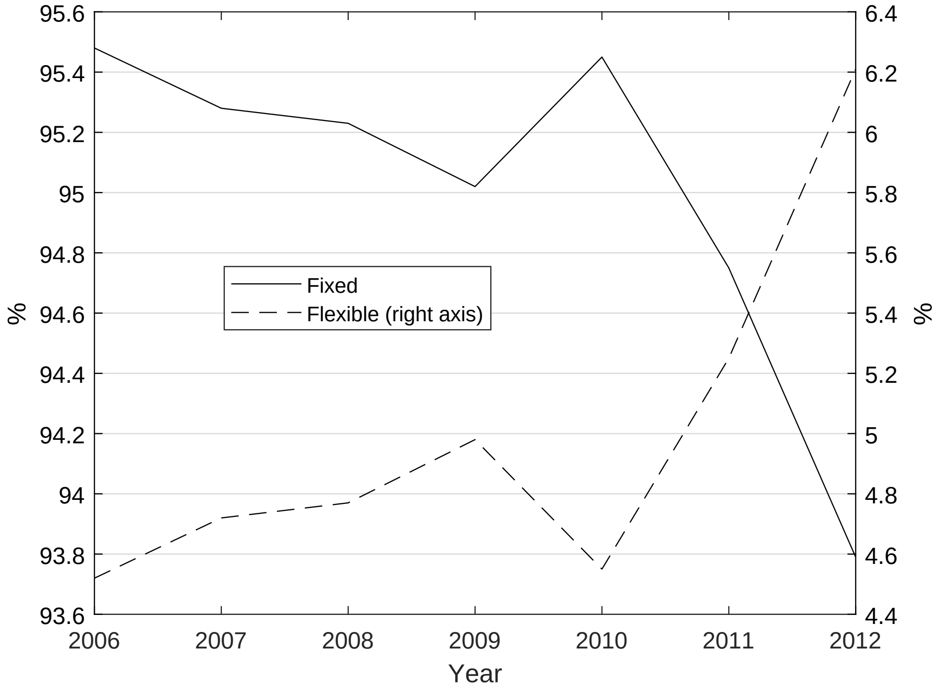


Figure 4.11: Participation of tenured and untenured contracts

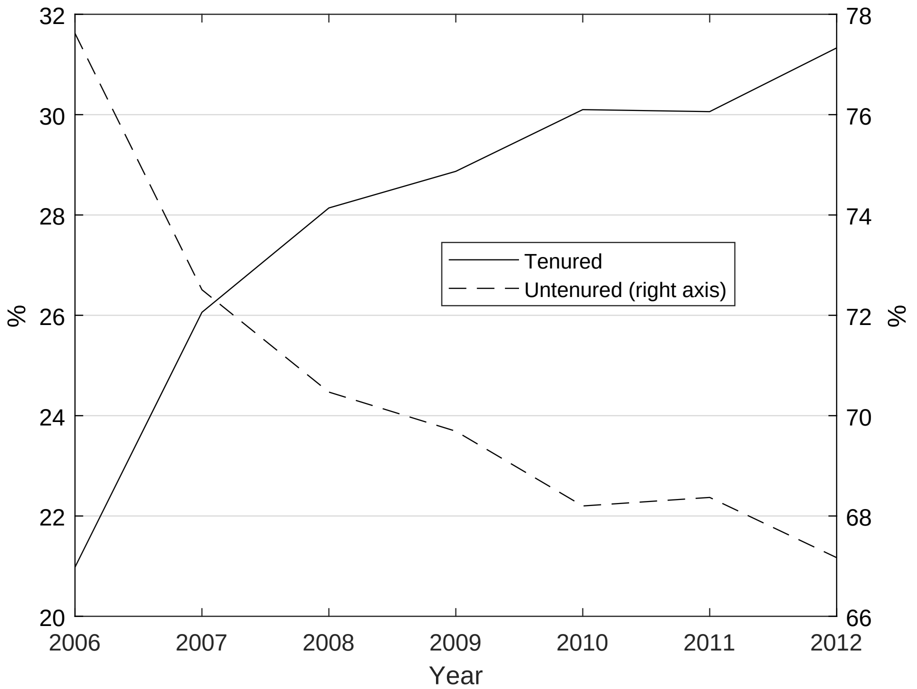
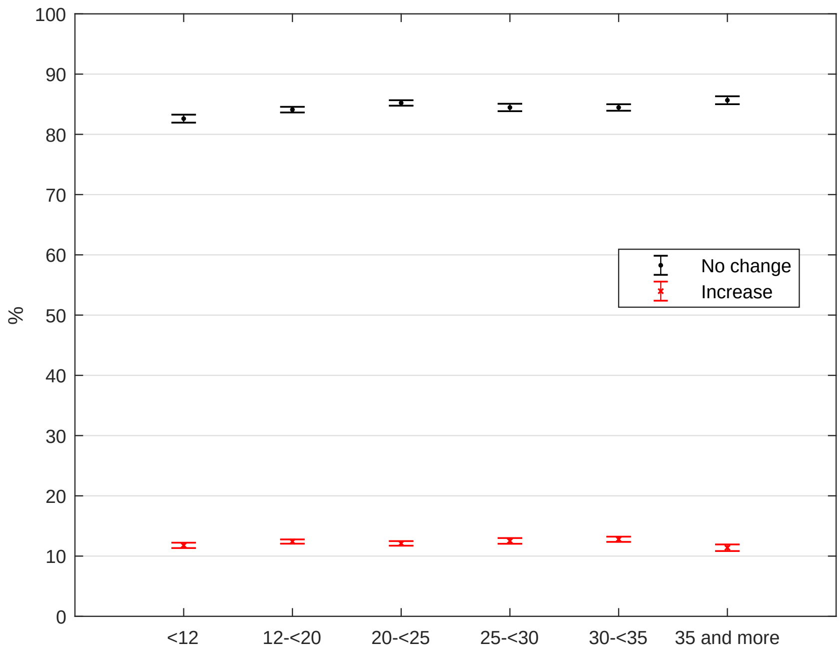


Figure 4.12: Weekly contract hours



Source: Own calculations.

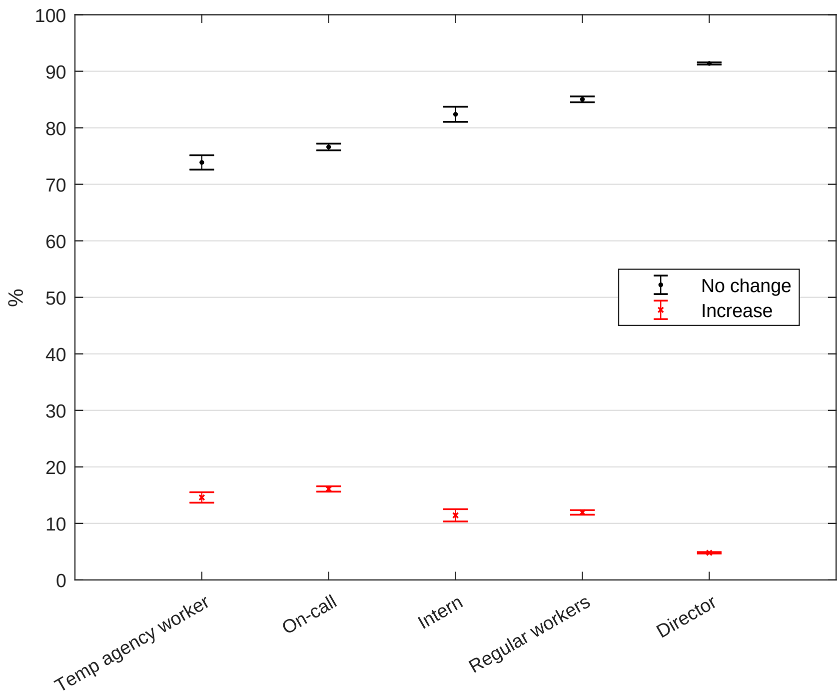
Next we unpack the contract details of employees and observe further interesting patterns in rigidities of wages across types & terms of contracts. First, in Figure 4.12 and Table 4.8 we show that the degree of wage rigidity is higher for employees working for more hours. For instance, while the likelihood of a no-change for the group of 35+ hours is 85.7%, the same likelihood is 82.6% for employees working for less than 12 hours a week. The downward rigidity drives a large portion of this difference in wages. Second, Figure 4.13 and Table 4.9 exhibit a clear positive correlation between "labor flexibility" and "wage flexibility". Specifically, wages of more flexible types of labor, such as temporary & on-call workers, is a lot less rigid compared to regular workers and directors. While the likelihood of no change in wages is 91.4% for directors, it is 73.9% for temporary workers. This difference is driven by differences in both downward and upward adjustments in wages. This observation is very relevant from a macro point of view because there has been an increase in the number of flexible labor positions in The Netherlands over the recent years. As Figure 4.14 shows, for instance, the percentage of on-call workers in the Netherlands more than doubled between 2003 and 2015, going from 3.8% to 8%, with respect to the total number of workers.

Table 4.8: Weekly contract hours

	Frequency			Average size	
	Decrease	**No change**	**Increase**	**Decrease**	**Increase**
<12	5.6 [5.3; 5.9]	82.6 [81.9; 83.3]	11.8 [11.3; 12.2]	-8.8	9.4
12-<20	3.5 [3.3; 3.7]	84.1 [83.6; 84.6]	12.4 [12.1; 12.8]	-8.8	5.4
20-<25	2.7 [2.5; 2.9]	85.2 [84.8; 85.7]	12.1 [11.7; 12.5]	-8.6	4.3
25-<30	3.0 [2.7; 3.3]	84.5 [83.8; 85.1]	12.5 [12.0; 13.0]	-8.2	4.3
30-<35	2.7 [2.4; 3.0]	84.5 [83.9; 85.0]	12.8 [12.4; 13.2]	-8.3	4.1
35 and more	3.0 [2.6; 3.3]	85.7 [85.0; 86.3]	11.4 [10.8; 11.9]	-9.6	4.2

Marginal effects from multinomial logit models. All the numbers are percentages, and rows sum up to a 100%. Confidence intervals in brackets. The last two columns represents the percentage change in nominal wage, conditional on a wage decrease or increase. The total number of observations is 13,174,294.

Figure 4.13: Type of job



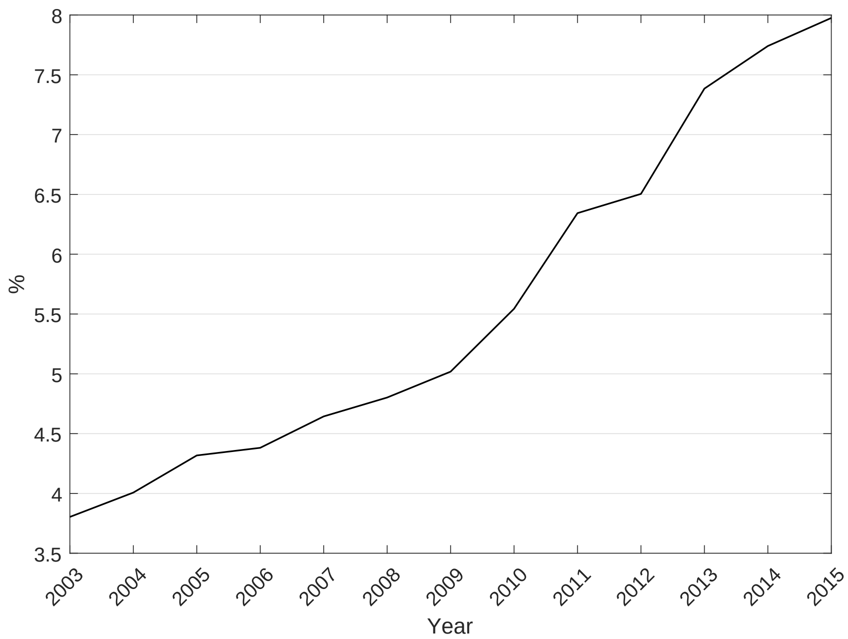
Source: Own calculations.

Table 4.9: Type of job

	Frequency			Average size	
	Decrease	**No change**	**Increase**	**Decrease**	**Increase**
Temp agency worker	11.5 [10.6; 12.5]	73.9 [72.6; 75.1]	14.6 [13.7; 15.5]	-20.8	5.9
On-call	7.3 [6.8; 7.8]	76.6 [76.0; 77.2]	16.1 [15.6; 16.6]	-5.3	5.8
Intern	6.2 [5.5; 6.9]	82.4 [81.0; 83.7]	11.4 [10.3; 12.5]	-24.9	22.3
Regular workers	3.0 [2.8; 3.3]	85.0 [84.5; 85.6]	11.9 [11.5; 12.3]	-8.8	4.7
Director	3.8 [3.7; 3.9]	91.4 [91.2; 91.6]	4.8 [4.7; 4.9]	-15.4	13.3

Marginal effects from multinomial logit models. All the numbers are percentages, and rows sum up to a 100%. Confidence intervals in brackets. The last two columns represents the percentage change in nominal wage, conditional on a wage decrease or increase. The total number of observations is 13,174,294.

Figure 4.14: Share of "on-call" in the total number of workers



Source: CBS - Netherlands.

4.6 Wage Rigidity: Time- and State-Dependency

As we have covered in Section 4.2, the well-known theories of state and time dependency propose different underlying reasons for changes in wages. Theories of state-dependency suggest that the probability of adjustments in wages moves with the state of the economic environment. Theories of time-dependency, in turn, argue that this probability depends on the temporal context, given by a specific period of the year, or the duration of the wage spell - and it is independent of the economic conditions.

The database at our disposal, with the benefits associated with a high periodicity, high disaggregation and ample information at the level of the employee as we described in Section 4.4, presents a unique opportunity to test which theory best explains the dynamics of nominal wages in the Netherlands. With this objective, we estimate the following fixed-effect model for the probability of observing a change in nominal wages - separately for reductions in wages and wage increases,

$$y_{i,t} = \alpha + \boldsymbol{q}_{i,t}\boldsymbol{\delta} + \boldsymbol{x}_{i,t}\boldsymbol{\beta} + \boldsymbol{z}_{i,t}\boldsymbol{\gamma} + \upsilon_i + \epsilon_{i,t}, \tag{4.1}$$

$$y_{i,t} = \begin{cases} 1 & \text{if } w_{i,t} \neq w_{i,t-1} \\ 0 & \text{if } w_{i,t} = w_{i,t-1} \end{cases}$$

where i is the wage trajectory, t is months and w is the nominal hourly wage.[14]

Equation (4.1) contains variables aimed to capture time- and state-dependent components of wage changes. Specifically, vector $\boldsymbol{q}$ captures the potential of time-dependency by including monthly and duration dummies. Vector $\boldsymbol{x}$ proxies the possibility of state-dependency by incorporating factors related to the macroeconomic environment and firm productivity. In particular, $\boldsymbol{x}$ includes accumulated inflation $\left(\pi_{t-1} - \pi_{t-\tau_{-1}}\right)$, accumulated unemployment variation $\left(u_{t-1} - u_{t-\tau_{-1}}\right)$ and a proxy for accumulated firm productivity, which is given by the change in the size of the firm - measured in terms of number of employees $\left(ne_{f,t-1} - ne_{f,t-\tau_{-1}}\right)$, with τ_{-1} being the duration of the wage spell.[15] These variables measure the accumulated disequilibrium between the optimal wage set at the beginning of the spell and current wage (Cecchetti (1987)).

The vector $\boldsymbol{z}$ comprises of characteristics of the wage trajectory and the business unit, which are employment policy, employment relationship, type of contract, type of relationship, contract hours, type of job, size of the business unit, and age of the employee.

4.6.1 Results: Time- vs. State-dependency

Table 4.10 shows the results, using the entire sample, in the case of wage increases. Column A shows the estimated values for the model that does not include dummy variables of duration, while column B includes dummy variables of duration for up to 12 periods.[16]

The estimated results confirm the evidence of seasonality in wage changes mentioned in Section 4.5. In this regard, a Wald test rejects the hypothesis that the coefficients associated with the monthly dummy variables are jointly not significant. The same test rejects the hypothesis that all the coefficients associated

[14] A wage trajectory is given by $y_i \equiv y_{ejf}$ with e representing employee, j employee's job and f is business unit. υ_i represents wage trajectory fixed effects.

[15] Sigurdsson and Sigurdardottir (2016) and Bihan, Montornès and Heckel (2012) include these variables as well, but in the context of a Tobit type II model that allows them, in addition, to model the size of wage changes. We have opted for a linear model due to computational constraints associated with the size of our sample. However, we verified, using a considerably smaller sample, that our results are comparable with those obtained with a Probit model, in line with the specification in Sigurdsson and Sigurdardottir (2016) and Bihan, Montornès and Heckel (2012).

[16] The model includes the complete set of dummy duration variables. Due to space restrictions, we only show a subset of them.

Table 4.10: Probability of a wage increase

	Panel A		Panel B	
	Parameter	**Standard error**	**Parameter**	**Standard error**
"Time depedency"				
Month				
January	0.326***	0.015	0.281***	0.013
February	0.069***	0.005	0.072***	0.006
March	0.017***	0.005	0.038***	0.005
April	0.026***	0.010	0.062***	0.009
May	0.000	0.006	0.034***	0.006
June	0.029***	0.008	0.055***	0.007
July	0.1***	0.015	0.105***	0.014
August	0.069***	0.011	0.067***	0.010
Setpember	0.017***	0.005	0.025***	0.005
October	0.019***	0.004	0.036***	0.005
November	-0.001***	0.003	0.01***	0.004
Duration				
1 month			0.006*	0.003
2 months			0.025***	0.004
3 months			0.051***	0.005
4 months			0.049***	0.005
5 months			0.066***	0.006
6 months			0.086***	0.006
7 months			0.077***	0.005
8 months			0.087***	0.006
9 months			0.101***	0.007
10 months			0.114***	0.007
11 months			0.399***	0.015
12 months			0.139***	0.013
"State dependency"				
Accumulated inflation	0.036***	0.002	0.007***	0.002
Accumulated unemployment	-0.014***	0.003	-0.03***	0.003
Accumulated productivity	0.000	0.000	0.000	0.000
Employment policy				
Part-time	-0.002	0.003	-0.002	0.003
Employment relationship				
Flexible	0.009	0.006	0.009	0.006
Type of contract				
Not applicable	-0.002	0.010	-0.010	0.011
Untenured	0.002	0.004	-0.005	0.005
Type of relationship				
Partnership	-0.006	0.005	-0.006	0.005
Single	-0.004**	0.002	-0.002	0.002
age	-0.016***	0.001	-0.014***	0.001
Weekly contract hours				
12-<20	0.003	0.002	0.002	0.002
20-<25	-0.002	0.003	-0.003	0.003
25-<30	-0.007*	0.004	-0.007**	0.004
30-<35	-0.008	0.005	-0.008*	0.005
35 and more	-0.034***	0.007	-0.035***	0.006
Business size				
2	-0.05*	0.026	-0.048*	0.027
3 to 4	-0.051*	0.027	-0.05*	0.028
5 to 9	-0.056**	0.028	-0.057**	0.029
10 to 19	-0.052*	0.029	-0.055*	0.030
20 to 49	-0.051*	0.031	-0.053*	0.032
50 to 99	-0.052	0.033	-0.055	0.035
100 to 149	-0.045	0.036	-0.049	0.037
150 to 199	-0.040	0.038	-0.043	0.039
200 to 249	-0.035	0.039	-0.038	0.041
250 to 499	-0.017	0.042	-0.020	0.044
500 to 999	-0.003	0.045	-0.009	0.047
1000 to 1999	0.028	0.043	0.025	0.045
2000 or more	0.041	0.046	0.043	0.048
Constant	0.727***	0.057	0.618***	0.066
Observations	4,707,989		4,707,989	

The reference wage trajectory is one from a worker with a full-time contract, fixed hours, tenured, married, working in a small business unit. Standard errors (in parenthesis) clustered at business unit level. *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

to the months are statistically equal and, instead, as shown in Table 4.10 wage increases are more likely to occur in January and July.

This pattern in the temporal behavior of wage increases represents evidence against Calvo's approach to determining wages (equal probability of observing a change in each period). The pattern seen in the estimate instead supports the notion of Taylor time dependence, in which wage changes occur at certain fixed time periods, and is in line with our findings in the analysis of the hazard function. The strong statistical significance of the dummy variables of duration, at 1% in almost all cases, reinforces the time-dependency component. It is worth noting that, unlike Sigurdsson and Sigurdardottir (2016), the dummy variables of duration maintain their effect on the probability of a wage increase even when the model takes the months into account as an independent variable.

We also find substantial evidence of state dependence. This empirical observation remains, although with a reduced magnitude in some cases, even after including duration dummies. In particular, as intuition suggests, we find a positive and statistically significant relationship between the probability of a wage increase and accumulated inflation. In the model without duration dummies, an increase in accumulated inflation of 1 percentage point (pp) increases the probability of an increase in wages by 3.6%. Once we include the duration dummies, the same change in accumulated inflation increases the probability of an increase in wages to 0.7%.[17]

Table 4.10 shows the expected negative sign for the accumulated unemployment coefficient. Here, and without duration dummies, an increase in accumulated unemployment of 1 pp decreases the probability of an increase in wages by 1.4%. In contrast to the aforementioned effect for accumulated inflation, including duration dummies amplifies the impact of accumulated unemployment. Specifically, when accumulated unemployment increases by 1 pp, the probability of an increase in wages decreases by 3.0%.[18,19]

[17] In the sample the average accumulated inflation is of 0.81 pp. The 99% percentile is 4.9 pp and the 1% percentile is -1.0 pp.

[18] In the sample the average accumulated unemployment is of 0.04 pp. The 99% percentile is 1.4 pp and the 1% percentile is -1.1pp.

[19] Regarding the controls, Table 4.10 shows that all the variables associated with the different characteristics of the contracts are not significant. In addition, there is a negative and significant relationship between the probability of an increase in wages and working hours for those who work over 25 hours a week. As in Bihan, Montornès and Heckel (2012), we detected weak evidence (10% of significance) of a negative link between the probability of a wage increase and the size of the business unit, when it has less than 50 persons employed. In the same line, and confirming our discussion in Section 4.5, the results show that age negatively affects the probability of a wage increase.

Table 4.11 shows the results, using the entire sample, for the case of wage reductions without (column A) and with (column B) duration dummies.

For wage reductions, we find similar results regarding the statistical significance of the seasonality variables and the duration dummies, both supporting the presence of time dependence. The Wald test rejects the hypothesis of no joint significance and the hypothesis of equality of the coefficients at 1%. The seasonal pattern does not present peaks as clear as in the case of wage increases; wage reductions are more likely to occur in January, but this probability is not very different from those observed in other months. In addition, it is more likely to see a wage reduction after a short period without wage changes (four months or fewer). These last two results are comparable to those found by Sigurdsson and Sigurdardottir (2016).

Overall, we find evidence of state-dependency which survives the incorporation of duration variables.[20] However, compared to the wage increase scenario, the effects of macroeconomic variables on the probability of wage reductions are of lesser magnitude. Specifically, Table 4.11 shows that on average (for models with and without dummy duration variables), an increase in accumulated inflation of 1 pp increases the probability of a wage reduction by 0.65%. Similarly, an increase in accumulated unemployment of 1 pp decreases the probability of a wage reduction by 0.35%.[21]

4.6.2 Results: Time- vs. State-dependency and contracts

In this section we investigate the time and state component in the probability of observing changes in wages based on the characteristics of employment contracts.

We find evidence of time dependence for all types of contracts considered. In this sense, and like when the estimate uses the pooled sample, Table 4.12 shows that in the case of wage increases, the seasonal pattern is also present when we break down the data by contractual characteristics.

[20] In contrast, Sigurdsson and Sigurdardottir (2016) found that the probability of a wage reduction does not respond to changes in current accumulated inflation or unemployment.

[21] Regarding the controls, Table 4.11 shows that, except for tenured workers (with a small positive relationship with the probability of a wage reduction), the variables associated with the characteristics of the contracts are not significant. In addition, wage reductions are less likely for workers who work less than 30 hours and for those who work over 35. We found no evidence of a link between the probability of a wage reduction and the size of the business unit. On the contrary, Bihan, Montornès and Heckel (2012) found that this probability is greater in small establishments. There is a positive but insignificant relationship between age and the possibility of a wage reduction.

Table 4.11: Probability of a wage reduction

	Panel A		Panel B	
	Parameter	**Standard error**	**Parameter**	**Standard error**
"Time depedency"				
Month				
January	0.029***	0.005	0.028***	0.005
February	-0.023***	0.003	-0.011***	0.003
March	-0.019***	0.003	-0.012***	0.003
April	-0.022***	0.002	-0.015***	0.002
May	-0.016***	0.003	-0.012***	0.003
June	-0.036***	0.003	-0.03***	0.003
July	-0.017***	0.003	-0.011***	0.003
August	-0.022***	0.003	-0.016***	0.003
Setpember	-0.025***	0.003	-0.02***	0.003
October	-0.024***	0.003	-0.02***	0.003
November	-0.023***	0.003	-0.022***	0.003
Duration				
1 month			0.024***	0.001
2 months			0.035***	0.002
3 months			0.055***	0.003
4 months			0.043***	0.002
5 months			0.032***	0.002
6 months			0.038***	0.002
7 months			0.032***	0.002
8 months			0.033***	0.002
9 months			0.038***	0.002
10 months			0.029***	0.002
11 months			0.044***	0.002
12 months			0.038***	0.002
"State dependency"				
Accumulated inflation	0.009***	0.001	0.005***	0.001
Accumulated unemployment	-0.004***	0.001	-0.003**	0.001
Accumulated productivity	0.000	0.000	0.000	0.000
Employment policy				
Part-time	0.001	0.002	0.000	0.002
Employment relationship				
Flexible	0.004	0.004	0.004	0.004
Type of contract				
Not applicable	0.008	0.007	0.007	0.007
Untenured	0.005***	0.001	0.004***	0.001
Type of relationship				
Partnership	0.001	0.003	0.001	0.003
Single	-0.004***	0.001	-0.003***	0.001
age	0.003***	0.000	0.003***	0.000
Weekly contract hours				
12-<20	-0.014***	0.001	-0.014***	0.001
20-<25	-0.011***	0.002	-0.011***	0.002
25-<30	-0.009***	0.003	-0.009***	0.003
30-<35	0.002	0.004	0.001	0.004
35 and more	0.011**	0.005	0.01**	0.005
Business size				
2	-0.011	0.009	-0.010	0.008
3 to 4	-0.010	0.009	-0.010	0.008
5 to 9	-0.006	0.010	-0.007	0.009
10 to 19	-0.002	0.010	-0.003	0.009
20 to 49	-0.002	0.010	-0.003	0.010
50 to 99	-0.002	0.011	-0.004	0.010
100 to 149	0.001	0.012	-0.001	0.011
150 to 199	0.000	0.013	-0.003	0.012
200 to 249	0.003	0.013	0.000	0.012
250 to 499	0.002	0.014	-0.002	0.013
500 to 999	-0.003	0.015	-0.008	0.014
1000 to 1999	-0.006	0.015	-0.012	0.013
2000 or more	0.007	0.018	0.001	0.017
Constant	-0.073***	0.021	-0.109***	0.020
Observations	4,316,234		4,316,234	

The reference wage trajectory is one from a worker with a full-time contract, fixed hours, tenured, married, working in a small business unit. Standard errors (in parenthesis) clustered at business unit level. *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

The magnitude of the seasonal component for almost all types of contracts is comparable to the aggregate case mentioned in Subsection 4.6.1 but is less pronounced for wage trajectories with flexible hours. The probability of observing a wage increase in January and July for workers with flexible hours is 14% and 6% higher than the probability of observing it in December; for the other contracts, they are 28% and 10% on average, respectively. In other words, the probability of observing a wage increase for contracts with flexible hours is flatter during the year and, therefore, is closer to Calvo?s assumption of equal probability of change in each period.

We observe something similar regarding the duration variables. For contracts with flexible hours, the probability of having an increase in wage after 11 months with no change is 25%. On average, this probability for other types of contracts is almost double (41%). This observation reinforces again the heterogeneity in wage adjustments between workers with different contractual terms.

In general, most types of contracts show dependence on the state associated with accumulated inflation and unemployment. The estimated coefficients have the expected sign and are similar between the types of contracts and those obtained with the aggregate data (Subsection 4.6.1). In this sense, it is worth highlighting some findings, nevertheless.

There are two types of contracts for which the state dependency is associated only with one of the two macroeconomic variables considered. In particular, Table 4.12 shows that for contracts with flexible hours there is no significant relationship between the probability of a wage increase and accumulated unemployment.

Arguably, a stronger dependence on time compensates for this disconnection from the evolution of unemployment since the coefficients associated with the duration dummies are greater for workers with flexible hours compared to those with other types of contracts. Similarly, for fixed-term contracts the probability of a wage increase does not respond to accumulated inflation and, at the same time, its relation to accumulated unemployment is of lesser magnitude. In the case of flexible hours contracts, a stronger response to the duration of the wage trajectory accompanies this weaker dependency of the state.

The link between the likelihood of a wage increase and accumulated inflation for full-time contracts is twice as strong as for part-time contracts. Specifically, while for full-time contracts the positive relationship with accumulated inflation

Table 4.12: Probability of wage increases by type of contract

	Employment policy				Employment relationship				Type of contract			
	Full-time		Part-time		Fixed		Flexible		Tenured		Untenured	
	Par.	St. error	Par.	St. error	Par.	St. error	Par.	St. error	Par.	St. error	Par.	St. error
"Time-depedency"												
Month												
January	0.311***	0.014	0.256***	0.013	0.285***	0.014	0.136***	0.011	0.263***	0.015	0.285***	0.015
February	0.08***	0.009	0.067***	0.005	0.071***	0.006	0.1***	0.025	0.085***	0.006	0.07***	0.007
March	0.036***	0.007	0.042***	0.004	0.038***	0.005	0.042***	0.009	0.043***	0.003	0.038***	0.005
April	0.073***	0.012	0.053***	0.006	0.062***	0.009	0.045***	0.010	0.064***	0.014	0.062***	0.009
May	0.027***	0.006	0.041***	0.007	0.034***	0.006	0.041***	0.013	0.055***	0.006	0.03***	0.007
June	0.064***	0.011	0.049***	0.006	0.056***	0.008	0.033***	0.012	0.048***	0.005	0.058***	0.009
July	0.101***	0.011	0.11***	0.017	0.106***	0.014	0.063***	0.013	0.1***	0.011	0.108***	0.015
August	0.055***	0.010	0.08***	0.011	0.069***	0.010	0.015	0.011	0.069***	0.015	0.068***	0.011
Setpember	0.019***	0.007	0.032***	0.004	0.025***	0.005	0.005	0.009	0.035***	0.006	0.023***	0.006
October	0.035***	0.006	0.038***	0.005	0.037***	0.005	0.011	0.009	0.042***	0.005	0.036***	0.005
November	0.004	0.005	0.016***	0.004	0.01***	0.004	0.036	0.025	0.023***	0.005	0.008**	0.004
Duration												
1 month	-0.002	0.005	0.014***	0.003	0.004	0.004	0.04***	0.003	0.02***	0.004	0.003	0.004
2 months	0.016***	0.006	0.036***	0.003	0.023***	0.004	0.075***	0.007	0.046***	0.007	0.022***	0.004
3 months	0.042***	0.007	0.064***	0.004	0.049***	0.005	0.092***	0.005	0.074***	0.007	0.048***	0.005
4 months	0.042***	0.006	0.062***	0.004	0.048***	0.005	0.086***	0.006	0.079***	0.006	0.046***	0.005
5 months	0.074***	0.008	0.064***	0.005	0.064***	0.006	0.106***	0.007	0.107***	0.011	0.061***	0.006
6 months	0.08***	0.007	0.1***	0.006	0.085***	0.006	0.117***	0.009	0.109***	0.006	0.086***	0.007
7 months	0.077***	0.006	0.085***	0.005	0.075***	0.005	0.125***	0.009	0.122***	0.006	0.073***	0.005
8 months	0.083***	0.008	0.098***	0.006	0.085***	0.006	0.176***	0.028	0.142***	0.008	0.082***	0.007
9 months	0.102***	0.009	0.109***	0.006	0.1***	0.007	0.149***	0.012	0.172***	0.012	0.094***	0.007
10 months	0.107***	0.008	0.13***	0.008	0.113***	0.007	0.166***	0.012	0.2***	0.014	0.106***	0.007
11 months	0.417***	0.017	0.388***	0.015	0.399***	0.015	0.254***	0.027	0.454***	0.028	0.398***	0.015
12 months	0.146***	0.014	0.145***	0.014	0.139***	0.013	0.166***	0.014	0.196***	0.015	0.138***	0.014
"State-dependency"												
Accumulated inflation	0.01***	0.002	0.005***	0.002	0.007***	0.002	0.007**	0.003	-0.001	0.002	0.009***	0.002
Accumulated unemployment	-0.028***	0.004	-0.031***	0.003	-0.03***	0.003	-0.008	0.007	-0.023***	0.003	-0.031***	0.003
Accumulated productivity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Type of relationship												
Partnership	-0.01*	0.006	-0.002	0.009	-0.005	0.005	-0.017	0.038	0.001	0.013	-0.008	0.006
Single	-0.003	0.002	0.000	0.003	-0.001	0.002	-0.006	0.013	0.002	0.004	-0.003	0.002
age	-0.015***	0.002	-0.014***	0.001	-0.014***	0.001	-0.022***	0.003	-0.02***	0.002	-0.014***	0.002
Weekly contract hours												
12-<20			0.001	0.002	0.001	0.002	0.008**	0.004	0.003	0.002	0.001	0.003
20-<25			-0.005*	0.003	-0.006*	0.003	0.008	0.005	0.003	0.003	-0.006*	0.003
25-<30			-0.011***	0.004	-0.01**	0.004	0.008	0.006	-0.001	0.004	-0.011**	0.004
30-<35	-0.015**	0.007	-0.013***	0.004	-0.01**	0.005	0.017**	0.008	0.002	0.004	-0.011**	0.006
35 and more	-0.054***	0.009	-0.045***	0.005	-0.036***	0.005	0.010	0.008	-0.024***	0.005	-0.037***	0.006
Business size												
2	-0.020	0.013	-0.079*	0.048	-0.045*	0.025	-0.115*	0.059	-0.119***	0.046	-0.025**	0.012
3 to 4	-0.025*	0.013	-0.081	0.049	-0.048*	0.026	-0.117*	0.062	-0.124***	0.047	-0.025**	0.012
5 to 9	-0.03**	0.013	-0.091*	0.051	-0.054**	0.027	-0.141**	0.064	-0.13***	0.049	-0.033***	0.012
10 to 19	-0.029**	0.013	-0.09*	0.053	-0.053*	0.028	-0.13*	0.068	-0.132***	0.051	-0.03**	0.013
20 to 49	-0.025*	0.014	-0.092	0.058	-0.052*	0.030	-0.124*	0.075	-0.137**	0.054	-0.026**	0.013
50 to 99	-0.022	0.015	-0.099	0.063	-0.053	0.032	-0.128	0.081	-0.156***	0.060	-0.023*	0.014
100 to 149	-0.015	0.016	-0.096	0.068	-0.047	0.034	-0.126	0.083	-0.158**	0.065	-0.015	0.015
150 to 199	-0.013	0.017	-0.085	0.072	-0.040	0.036	-0.089	0.092	-0.168**	0.072	-0.005	0.016
200 to 249	0.003	0.018	-0.085	0.075	-0.035	0.038	-0.194*	0.100	-0.163**	0.075	0.003	0.017
250 to 499	0.015	0.017	-0.066	0.079	-0.017	0.040	-0.125	0.106	-0.161*	0.088	0.023	0.016
500 to 999	0.034***	0.012	-0.061	0.084	-0.005	0.043	-0.176	0.130	-0.196*	0.108	0.038***	0.014
1000 to 1999	0.058***	0.012	-0.021	0.084	0.031	0.041	-0.174	0.133	-0.151	0.105	0.072***	0.016
2000 or more	0.073***	0.014	0.001	0.088	0.049	0.044	-0.193	0.135	-0.153	0.110	0.092***	0.024
Constant	0.656***	0.069	0.649***	0.085	0.61***	0.066	0.944***	0.102	0.847***	0.067	0.61***	0.066
Observations	2,242,959		2,465,030		4,579,206		128,783		835,661		3,816,496	

Standard errors clustered at business unit level. *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

is one to one, an increase of the latter by 1 percentage point only increases the probability of a wage increase for part-time contracts by 0.5%.[22]

Table 4.13 shows the estimated results, disaggregated by type of contracts, for the case of wage reductions.

With the exception of flexible-hours contracts, which show a decrease in the probability of observing a wage reduction in January (with respect to December), the observed seasonality pattern is similar to that analyzed in Subsection 4.6.1. The negative relationship between the probability of a wage reduction and the variable associated with the months is considerably stronger throughout the year for this type of contract. The link between this probability and the duration variables is also stronger for flexible-hours contracts (on average it is three times higher).

The probability of a wage reduction also presents a component of state dependence, particularly evident for part-time and tenured contracts. Compared with the other types of contracts, the former shows a negative effect of accumulated unemployment that is almost 1.5 times higher. Likewise, the positive effect of accumulated inflation for tenured contracts is almost double that of contracts with other characteristics. On the contrary, for full-time and tenured contracts, accumulated unemployment does not affect the probability of a wage reduction.[23]

4.7 Concluding Remarks

Nominal wage rigidities not only impede the achievement of an optimal allocation of resources but also exacerbate unwanted fluctuations in unemployment and output, among other macroeconomic variables. These negative repercussions open the door to monetary policy interventions, which, however, can only counteract their effects when the determinants and magnitude of nominal wage rigidities are understood and measured correctly.

Understanding the way in which nominal wages are determined and the possible frictions that prevent them from adjusting to their optimum levels is, therefore, an important task for macroeconomists. However, only recently available databases, with high periodicity and a high level of disaggregation, have allowed

[22] In regard to the controls, Table 4.12 shows that only for tenured contracts the size of the business unit has a significant (negative) relationship with the probability of a wage increase.

[23] In general, there is a negative relationship between the hours worked per week and the probability of a wage reduction. This is stronger for flexible-hours contracts.

Table 4.13: Probability of wage reductions by type of contract

	Employment policy				**Employment relationship**				**Type of contract**			
	Full-time		**Part-time**		**Fixed**		**Flexible**		**Tenured**		**Untenured**	
	Par.	**St. error**	**Par.**	**St. error**	**Par.**	**St. error**	**Par.**	**St. error**	**Par.**	**St. error**	**Par.**	**St. error**
"Time-depedency"												
Month												
January	0.034***	0.006	0.022***	0.005	0.029***	0.005	-0.014	0.008	0.015***	0.005	0.031***	0.005
February	-0.014***	0.003	-0.011***	0.003	-0.012***	0.003	-0.042***	0.005	-0.01***	0.003	-0.011***	0.003
March	-0.014***	0.003	-0.01***	0.003	-0.011***	0.003	-0.051***	0.006	-0.015***	0.003	-0.01***	0.003
April	-0.013***	0.003	-0.017***	0.003	-0.014***	0.002	-0.059***	0.005	-0.023***	0.003	-0.013***	0.003
May	-0.009***	0.003	-0.015***	0.003	-0.011***	0.003	-0.062***	0.006	-0.021***	0.004	-0.01***	0.003
June	-0.032***	0.004	-0.029***	0.003	-0.03***	0.003	-0.059***	0.005	-0.04***	0.004	-0.028***	0.003
July	-0.014***	0.004	-0.009***	0.003	-0.01***	0.003	-0.049***	0.006	-0.014***	0.004	-0.01***	0.003
August	-0.021***	0.004	-0.011***	0.003	-0.015***	0.003	-0.054***	0.006	-0.018***	0.004	-0.015***	0.003
Setpember	-0.025***	0.004	-0.015***	0.003	-0.019***	0.003	-0.056***	0.006	-0.023***	0.004	-0.018***	0.003
October	-0.025***	0.004	-0.016***	0.003	-0.019***	0.003	-0.056***	0.005	-0.026***	0.003	-0.018***	0.004
November	-0.028***	0.004	-0.016***	0.003	-0.022***	0.003	-0.028***	0.005	-0.024***	0.003	-0.021***	0.004
Duration												
1 month	0.02***	0.001	0.027***	0.001	0.022***	0.001	0.073***	0.003	0.038***	0.002	0.019***	0.001
2 months	0.028***	0.002	0.041***	0.002	0.032***	0.002	0.122***	0.005	0.057***	0.003	0.03***	0.002
3 months	0.05***	0.003	0.06***	0.003	0.052***	0.003	0.142***	0.006	0.083***	0.005	0.048***	0.003
4 months	0.033***	0.002	0.054***	0.003	0.041***	0.002	0.123***	0.005	0.067***	0.004	0.038***	0.002
5 months	0.027***	0.002	0.039***	0.002	0.03***	0.002	0.128***	0.008	0.059***	0.004	0.027***	0.002
6 months	0.03***	0.003	0.047***	0.002	0.035***	0.002	0.128***	0.010	0.064***	0.004	0.033***	0.003
7 months	0.025***	0.002	0.041***	0.002	0.03***	0.001	0.121***	0.010	0.058***	0.004	0.027***	0.001
8 months	0.026***	0.002	0.042***	0.003	0.031***	0.002	0.127***	0.009	0.058***	0.004	0.028***	0.002
9 months	0.028***	0.002	0.05***	0.003	0.036***	0.002	0.111***	0.011	0.065***	0.005	0.033***	0.002
10 months	0.023***	0.002	0.036***	0.002	0.027***	0.002	0.104***	0.011	0.06***	0.004	0.024***	0.002
11 months	0.041***	0.003	0.047***	0.003	0.041***	0.002	0.117***	0.013	0.068***	0.005	0.037***	0.002
12 months	0.029***	0.003	0.047***	0.002	0.036***	0.002	0.11***	0.012	0.06***	0.005	0.034***	0.002
"State-dependency"												
Accumulated inflation	0.006***	0.001	0.004***	0.001	0.005***	0.001	0.006***	0.002	0.008***	0.001	0.004***	0.001
Accumulated unemployment	-0.001	0.001	-0.004***	0.001	-0.003***	0.001	0.009**	0.005	-0.003	0.002	-0.002**	0.001
Accumulated productivity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Type of relationship												
Partnership	-0.002	0.003	0.005	0.004	0.001	0.003	-0.003	0.079	0.012	0.008	0.000	0.003
Single	-0.004***	0.001	-0.002	0.001	-0.004***	0.001	-0.024**	0.012	0.001	0.003	-0.004***	0.001
age	0.002***	0.000	0.003***	0.000	0.003***	0.000	0.01***	0.002	0.005***	0.001	0.003***	0.000
Weekly contract hours												
12-<20			-0.012***	0.002	-0.01***	0.001	-0.024***	0.004	-0.021***	0.003	-0.009***	0.002
20-<25			-0.008***	0.003	-0.006**	0.002	-0.032***	0.005	-0.025***	0.003	-0.004	0.003
25-<30			-0.005	0.004	-0.003	0.003	-0.044***	0.005	-0.026***	0.004	-0.002	0.003
30-<35	0.018***	0.004	0.01**	0.005	0.008*	0.004	-0.058***	0.007	-0.018***	0.005	0.01**	0.004
35 and more	0.033***	0.005	0.016**	0.007	0.017***	0.006	-0.047***	0.007	-0.006	0.006	0.019***	0.006
Business size												
2	-0.007	0.009	-0.005	0.006	-0.009	0.008	-0.007	0.021	0.004	0.009	-0.016*	0.008
3 to 4	-0.007	0.009	-0.006	0.006	-0.009	0.008	-0.007	0.020	0.008	0.008	-0.016*	0.008
5 to 9	-0.005	0.010	0.000	0.006	-0.006	0.008	-0.004	0.020	0.010	0.008	-0.014	0.009
10 to 19	0.000	0.010	0.002	0.007	-0.003	0.009	0.008	0.021	0.012	0.008	-0.010	0.009
20 to 49	-0.002	0.010	0.003	0.007	-0.004	0.009	0.024	0.022	0.009	0.009	-0.011	0.009
50 to 99	-0.003	0.011	0.004	0.008	-0.005	0.010	0.035	0.027	0.014	0.010	-0.013	0.010
100 to 149	-0.002	0.012	0.010	0.008	-0.002	0.011	0.040	0.028	0.02*	0.011	-0.011	0.010
150 to 199	-0.002	0.012	0.008	0.008	-0.004	0.011	0.050	0.031	0.023**	0.011	-0.015	0.011
200 to 249	0.005	0.013	0.006	0.009	-0.001	0.012	0.075	0.054	0.043***	0.014	-0.013	0.011
250 to 499	-0.005	0.013	0.010	0.009	-0.004	0.012	0.049	0.035	0.016	0.011	-0.013	0.011
500 to 999	-0.016	0.013	0.007	0.009	-0.010	0.013	0.065**	0.026	0.005	0.010	-0.018	0.011
1000 to 1999	-0.024**	0.012	0.007	0.010	-0.014	0.013	0.047*	0.027	0.003	0.010	-0.021*	0.011
2000 or more	-0.013	0.019	0.023	0.015	-0.001	0.017	0.073***	0.027	0.029	0.018	-0.009	0.016
Constant	-0.091***	0.020	-0.134***	0.019	-0.112***	0.020	-0.285***	0.057	-0.18***	0.031	-0.108***	0.020
Observations	2,054,190		2,262,044		4,195,818		120,416		771,440		3,489,291	

Standard errors clustered at business unit level. *** Significant at the 1 percent level, ** Significant at the 5 percent level, * Significant at the 10 percent level.

us to overcome the previous difficulties associated with understanding and measuring the dynamics of nominal wage changes.

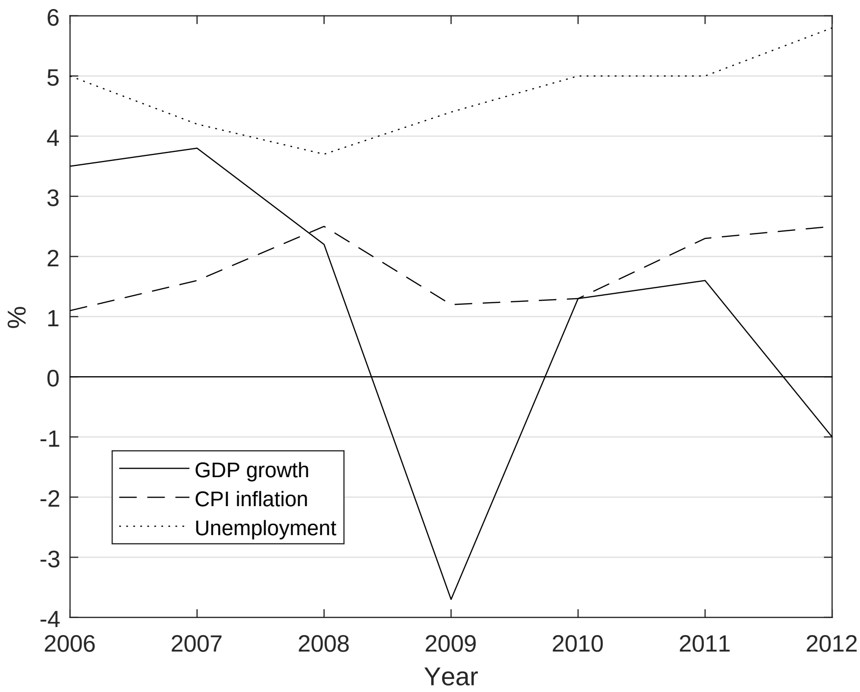
This paper helps shed some light on the determinants and magnitude of nominal wage rigidities. We explored the dynamics of nominal wage rigidities in the Netherlands using a high frequency micro database with monthly information on nominal wages and the characteristics of the employment contracts of all employees in the period 2006-2012.

Several results stand out. We documented a clear seasonal pattern in the degree of nominal wage rigidity and a momentary increase in this rigidity immediately after the recent financial crisis. Our results also show a significant variability in the frequency of nominal wage changes in the different sectors, according to the size of the business unit and according to the age of the employee. In addition, we found that the hazard function has two peaks, one at 12 months and another at 24 months.

More importantly, and as a unique contribution, we find that certain characteristics of labor contracts play a role in determining the degree of nominal wage rigidity. In particular, characteristics such as the type of job, the working time, the duration of the contract and the status of the employee are an important source of heterogeneity in the nominal wage rigidity. As far as we know, this is the first time that the relationship between these contractual characteristics and the nominal wage rigidity is empirically uncovered.

In addition, our analysis provides evidence in favor of the theories of time- and state-dependence in the determination of nominal wages. We find that the probability of a change in the nominal wage depends on the duration of the wage trajectory (and the specific month of the year) but also on the evolution of aggregate macroeconomic variables (unemployment and inflation). This result is maintained, in general, when we perform the analysis separately for the different types of contracts, with some exceptions. In this sense, we find, on the one hand, that the probability of a wage increase in flexible hours contracts and in tenured contracts only responds to one of the two macroeconomic variables considered: inflation and unemployment, respectively. On the other hand, our results show that the probability of a nominal wage increase in full-time contracts shows a considerably higher response to changes in inflation and unemployment compared to the way part-time contracts respond.

Figure 4.15: Macroeconomic series for The Netherlands



4.8 Appendix

4.8.1 Additional figure

4.8.2 Additional tables

Table 4.14: Distribution of contracts based on wage trajectory

	Director	**Intern**		**SWS-er**		**Temp. workers**		**On-call**		**Rest**		**Total**
	NA	**T**	**U**	**T**	**U**	**T**	**U**	**T**	**U**	**T**	**U**	
Full-time												
Fixed hours	1.2	0.2	0.1	0.1	0.3					16.0	36.7	54.5
Flexible hours						0.9	0.2	0.6	0.5			2.2
Part-time												
Fixed hours	0.3	0.1	0.0	0.1	0.2					13.9	23.5	38.0
Flexible hours						0.5	0.1	2.6	2.2			5.3
Total	1.5	0.2	0.1	0.1	0.4	1.4	0.2	3.2	2.7	29.9	60.2	
		0.4		0.6		1.6		5.9		90.1		
% working overtime	0.3	0.8	1.0		0.1	12.2	7.6	1.7	1.8	3.0	6.2	4.8
		0.9		0.1		11.6		1.7		5.0		

T: Tenured, U: Untenured, NA: Not aplicable. The total number of wage trajectories is 567,130. All the numbers are percentages.

Table 4.15: Distribution of contracts based on observations

	Director	**Intern**		**SWS-er**		**Temp. workers**		**On-call**		**Rest**		**Total**
	NA	**T**	**U**	**T**	**U**	**T**	**U**	**T**	**U**	**T**	**U**	
Full-time												
Fixed hours	1.2	0.0	0.0	0.0	0.7					8.9	36.5	47.4
Flexible hours						0.2	0.1	0.1	0.1			0.5
Part-time												
Fixed hours	0.4	0.0	0.0	0.1	0.4					10.7	37.4	49.0
Flexible hours						0.3	0.0	1.3	1.5			3.1
Total	1.6	0.1	0.0	0.2	1.1	0.5	0.1	1.4	1.6	19.6	73.9	
		0.1		1.3		0.6		3.0		93.5		
% working overtime	0.4	2.3	2.9	0.0	0.0	14.1	12.3	2.1	2.4	5.7	7.7	6.9
		2.6		0.0		13.8		2.2		7.3		

T: Tenured, U: Untenured, NA: Not aplicable. The total number of observations is 13,174,294. All the numbers are percentages.

Table 4.16: Number of observations lost in each step of the data cleaning process (5% sample)

Step	# of observations	# observation lost
Raw data	26,384,601	
Elimination of meaningless values	21,515,162	4,869,439
Elimination of percentiles 1% and 99%	21,327,537	187,625
Possible elimination of the first and last observation per wage trajectory	20,623,277	704,260
Elimination of wage trajectories of less than 3 months	20,190,719	432,558
Elimination of excessively volatile wage trajectories	14,905,628	5,285,091
Correction of wage trajectories with a "V" or inverted-"V" shape	14,905,628	0
Correction of spurious wage reversals	14,905,628	0

Table 4.17: Sector

	Frequency			Average size	
	Decrease	No change	Increase	Decrease	Increase
Private companies	4.1 [3.9; 4.3]	84.4 [84.0; 84.8]	11.5 [11.0; 12.0]	-9.0	5.5
Subsidized sector	2.7 [2.2; 3.2]	83.7 [82.7; 84.7]	13.6 [12.9; 14.3]	-8.7	4.1
Education	1.8 [1.5; 2.1]	87.1 [86.3; 88.0]	11.1 [10.5; 11.6]	-12.5	5.4
Municipalities	1.1 [0.9; 1.4]	87.6 [87.2; 88.0]	11.3 [11.0; 11.6]	-4.7	2.4

Marginal effects from multinomial logit models. All the numbers are percentages, and rows sum up to a 100%. Confidence intervals in brackets. The last two columns represents the percentage change in nominal wage, conditional on a wage decrease or increase. The total number of observations is 13,174,294.

Bibliography

Adjemian, Stéphane, Hutan Bastani, Michel Juillard, Frédéric Karamé, Ferhat Mihoubi, George Perendia, Johannes Pfeifer, Marco Ratto, and Sébastian Villemot. 2011. "Dynare: Reference manual, version 4." *Dynare Working Paper, CEPREMAP*, 1. 13, 57

Altig, David, Lawrence Christiano, Martin Eichenbaum, and Jesper Linde. 2002. "Technology Shocks and Aggregate Fluctuations." *Unpublished draft paper.* 12, 35

Altonji, Jg, and Pj Devereux. 2000. "The extent and consequences of downward nominal wage rigidity." *Research and Labor Economics*, 19(Worker Well-Being): 383–431. 88

Alvarez, Luis, Emmanuel Dhyne, Marco Hoeberichts, Claudia Kwapil, Hervé Le Bihan, Patrick Lünnemann, Fernando Martins, Roberto Sabbatini, Harald Stahl, Philip Vermeulen, and Vilmunen Jouko. 2006. "Sticky prices in the Euro Area: A summary of new micro-evidence." *Journal of the European Economic Association*, 4(May): 575–584. 8

Amato, Jeffery D., and Thomas Laubach. 2003*a*. "Estimation and control of an optimization-based model with sticky prices and wages." *Journal of Economic Dynamics and Control*, 27(7): 1181–1215. 21

Amato, Jeffery D., and Thomas Laubach. 2003*b*. "Rule-of-thumb behaviour and monetary policy." *European Economic Review*, 47(5): 791–831. 49

Andersen, Torben M. 1998. "Persistency in sticky price models." *European Economic Review*, 42(3-5): 593–603. 12

Andrés, Javier, David López-Salido, and Edward Nelson. 2005. "Sticky-Price Models and the Natural Rate Hypothesis." *Working paper. Federal Reserve Bank of St. Louis.* 26

Angeloni, Ignazio, Luc Aucremanne, Michael Ehrmann, Jordi Galí, Andrew Levin, and Frank Smets. 2006. "New evidence on inflation persistence and price stickiness in the euro area: implications for macro modeling." *Journal of the European Economic Association*, 4: 562–574. 8

An, Sungbae, and Frank Schorfheide. 2007. "Bayesian Analysis of DSGE Models." *Econometric Reviews*, 26(2-4): 113–172. 22

Aoki, Kosuke. 2001. "Optimal monetary policy responses to relative-price changes." *Journal of Monetary Economics*, 48: 55–80. 6, 8

Ascari, Guido, Andrea Colciago, and Lorenza Rossi. 2016. "Limited Asset Market Participation, Sticky Wages, and Monetary Policy." *Economic Inquiry*. 49, 50, 76

Azariadis, Costas. 1975. "Implicit Contracts and Underemployment Equilibria." *The Journal of Political Economy*, 83(6): 1183–1202. 89

Barattieri, Alessandro, Susanto Basu, and Peter Gottschalk. 2014. "Some Evidence on the Importance of Sticky Wages." *American Economic Journal: Macroeconomics*, 6(1): 70–101. 10, 88, 95, 96, 98, 99

Bartolomeo, Giovanni Di, and Lorenza Rossi. 2007. "Effectiveness of monetary policy and limited asset market participation: Neoclassical versus Keynesian effects." *International Journal of Economic Theory*, 3(Prin 2005): 213–218. 49

Bartolomeo, Giovanni Di, Lorenza Rossi, and Massimiliano Tancioni. 2011. "Monetary policy, rule-of-thumb consumers and external habits: a G7 comparison." *Applied Economics*, 43(21): 2721–2738. 47

Basu, Susanto, and Brent Bundick. 2015. "Endogenous Volatility at the Zero Lower Bound: Implications for Stabilization Policy." *The Federal Reserve Bank of Kansas City. Research Working Papers*, , (January). 46

Bihan, Hervé Le, Jérémi Montornès, and Thomas Heckel. 2012. "Sticky Wages: Evidence from Quarterly Microeconomic Data." *American Economic Journal: Macroeconomics*, 4(3): 1–32. 9, 88, 89, 95, 98, 99, 100, 104, 113, 115, 116

Bi, Huixin, and Michael Kumhof. 2011. "Jointly optimal monetary and fiscal policy rules under liquidity constraints." *Journal of Macroeconomics*, 33(3): 373–389. 49

Bilbiie, Florin O. 2008. "Limited asset markets participation, monetary policy and (inverted) aggregate demand logic." *Journal of Economic Theory*, 140(1): 162–196. 49

Bilbiie, Florin O., and Roland Straub. 2013. "Asset Market Participation, Monetary Policy Rules, and the Great Inflation." *Review of Economics and Statistics*, 95(2): 377–392. 47

Bils, Mark, and Peter J. Klenow. 2004. "Some evidence on the importance of sticky prices." *Journal of Political Economy*, 112(5). 8

Bils, Mark, and Yongsung Chang. 2003. "Welfare costs of sticky wages when effort can respond." *Journal of Monetary Economics*, 50: 311–330. 49

Calmfors, Lars, and Asa Johansson. 2006. "Nominal wage flexibility, wage indexation and monetary union." *The Economic Jornal*, 116: 283–308. 49

Calvo, Guillermo. 1983. "Staggered prices in a utility-maximizing framework." *Journal of monetary Economics*, 12(1978). 5, 12, 40, 51, 54, 91

Campbell, Carl, and Kunal Kamlani. 1997. "The Reasons for Wage Rigidity: Evidence From a Survey of Firms." *The Quarterly Journal of Economics*, 112(3): 759–789. 89

Campbell, JY, and N Gregory Mankiw. 1989. "Consumption, income and interest rates: Reinterpreting the time series evidence." *NBER Macroeconomics Annual 1989*, 4: 185–246. 47

Canova, Fabio. 2007. *Methods for Applied Macroeconomic Research.* Princeton University Press. 22

Caplin, Andrew, and Daniel Spulber. 1987. "Menu Cost and the Neutrality of Money." *The Quarterly Journal of Economics*, 102(4): 703–726. 91

Caplin, Andrew, and John Leahy. 1991. "State-dependent pricing and the dynamics of money and output." *The Quarterly Journal of Economics*, 106(3): 683–708. 40

Carlsson, Mikael, and Oskar Nordström Skans. 2012. "Evaluating Microfoundations for Aggregate Price Rigidities: Evidence from Matched Firm-Level Data on Product Prices and Unit Labor Cost." *American Economic Review*, 102(4): 1571–1595. 8, 26

Carvalho, Carlos. 2006. "Heterogeneity in Price Stickiness and the Real Effects of Monetary Shocks." *The B.E. Journal of Macroeconomics*, 6(3): 1–58. 6, 8

Cecchetti, Stephen G. 1987. "Indexation and Incomes Policy: A Study of Wage Adjustment in Unionized Manufacturing." *Journal of Labor Economics*, 5(3): 391–412. 113

Christiano, Lawrence, Martin Eichenbaum, and Charles Evans. 1999. "Monetary policy shocks: What have we learned and to what end?" *Handbook of macroeconomics*. 12, 35

Christiano, Lawrence, Martin Eichenbaum, and Charles Evans. 2005. "Nominal rigidities and the dynamic effects of a shock to monetary policy." *Journal of political Economy*, 113(1): 1–45. 2, 12, 26, 29, 35

Christoffel, Kai, and Tobias Linzert. 2010. "The role of real wage rigidity and labor market frictions for inflation persistence." *Journal of Money, Credit and Banking*, 42(7): 1435–1446. 39

Coenen, Günter, and Roland Straub. 2005. "Non-Ricardian Households and Fiscal Policy in an Estimated DSGE Model of the Euro Area." *Computing in Economics and Finance*, 102. 47

Coibion, Olivier, and Yuriy Gorodnichenko. 2011. "Strategic interaction among heterogeneous price-setters in an estimated DSGE model." *Review of Economics and Statistics*, 93(August): 920–940. 3, 6, 8, 9, 12, 13, 23, 26, 31, 39, 41

Colciago, Andrea. 2011. "Rule-of-Thumb Consumers Meet Sticky Wages." *Journal of Money, Credit and Banking*, 43(2). 49, 53

Colciago, Andrea, Tiziano Ropele, V. Anton Muscatelli, and Patrizio Tirelli. 2008. "The role of fiscal policy in a monetary union: Are national automatic stabilizers effective?" *Review of International Economics*, 16(3): 591–610. 47

De Graeve, Ferre. 2008. "The external finance premium and the macroeconomy: US post-WWII evidence." *Journal of Economic Dynamics and Control*, 32(11): 3415–3440. 29

DeJong, David, and Chetan Dave. 2011. *Structural Macroeconometrics, 2nd edition.* Princeton University Press. 22

DeJong, David N., Beth F. Ingram, and Charles H. Whiteman. 2000. "A Bayesian approach to dynamic macroeconomics." *Journal of Econometrics*, 98(2): 203–223. 22

Demirguc-Kunt, Asli, Leora Klapper, Dorothe Singer, Saniya Ansar, and Jake Hess. 2018. *The Global Findex Database 2017: Measuring Financial Inclusion and the Fintech Revolution.* 47

Dhyne, Emmanuel, Luis Alvarez, Hervé Le Bihan, Giovanni Veronese, Daniel Dias, Johannes Hoffmann, Nicole Jonker, Patrick Lünnemann, Fabio Rumler, and Vilmunen Jouko. 2006. "Price changes in the euro area and the United States: Some facts from individual consumer price data." *Journal of Economic Perspectives*, 20(2): 171–192. 8

Dickens, William T, Lorenz Goette, Erica L Groshen, Steinar Holden, Julian Messina, Mark E Schweitzer, Jarkko Turunen, and Melanie E Ward. 2007. "How Wages Change: Micro Evidence from the International Wage Flexibility Project." *Journal of Economic Perspectives*, 21(2): 195–214. 88

Dixon, Huw, and Hervé Le Bihan. 2012. "Generalized Taylor and Generalized Calvo Price and Wage Setting: Micro-Evidence with Macro Implications." *The Economic Journal*, 122: 532–54. 11

Druant, Martine, Silvia Fabiani, Gabor Kezdi, Ana Lamo, Fernando Martins, and Roberto Sabbatini. 2009. "How are firms' wages and prices linked: survey evidence in Europe." *Working paper series, European Central Bank*, 1084. 31

Druant, Martine, Silvia Fabiani, Gabor Kezdi, Ana Lamo, Fernando Martins, and Roberto Sabbatini. 2012. "Firms' price and wage adjustment in Europe: Survey evidence on nominal stickiness." *Labour Economics*, 19(5): 772–782. 10

ECB. 2012. "ECB Monthly Bulletin." European Central Bank August. 45

Edge, Rochelle, Thomas Laubach, and John Williams. 2003. "The Responses of Wages and Prices to Technology Shocks." *FRB of San Francisco Working Paper*. 35

Ehrlich, Gabriel, and Joshua Montes. 2017. "Wage Rigidity and Employment Outcomes: Evidence from Administrative Data." *Working Paper*. 88

Erceg, Christopher, DW Henderson, and Andrew Levin. 2000. "Optimal monetary policy with staggered wage and price contracts." *Journal of monetary Economics*, 46. 2, 21

Fehr, Ernst, and Lorenz Goette. 2005. "Robustness and real consequences of nominal wage rigidity." *Journal of Monetary Economics*, 52(4): 779–804. 88, 91

Fernández-Villaverde, Jesús. 2010. "The econometrics of DSGE models." *SERIEs*, 1(1-2): 3–49. 22

Fernández-Villaverde, Jesús, Grey Gordon, Pablo Guerrón-Quintana, and Juan Rubio-Ramírez. 2015. "Nonlinear adventures at the zero lower bound." *Journal of Economic Dynamics and Control*, 57. 46

Fischer, Stanley. 1977. "Long-Term Contracts, Rational Expectations, and the Optimal Money Supply Rule." *Journal of Political Economy*, 85(1): 191–205. 89, 91

Forni, Lorenzo, Libero Monteforte, and Luca Sessa. 2009. "The general equilibrium effects of fiscal policy: Estimates for the Euro area." *Journal of Public Economics*, 93(3-4): 559–585. 47

Friedman, Milton, and Anna Schwartz. 1963. *A Monetary History of the United States, 1867-1960.* Princeton, N.J.:Princeton University Press. 1

Furlanetto, Francesco. 2011. "Fiscal stimulus and the role of wage rigidity." *Journal of Economic Dynamics and Control*, 35(4): 512–527. 49

Furlanetto, Francesco, and Martin Seneca. 2012. "Rule-of-Thumb Consumers, Productivity, and Hours." *Scandinavian Journal of Economics*, 114(2): 658–679. 49

Galí, Jordi. 2008. *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework.* Princeton University Press. 21, 23, 26

Galí, Jordi. 2013. "Notes for a New Guide To Keynes (I): Wages, Aggregate Demand, and Employment." *Journal of the European Economic Association*, 11(October): 973–1003. 7, 39, 45, 46, 49, 76, 79

Galí, Jordi, and Tommaso Monacelli. 2014. "Understanding the Gains from Wage Flexibility: The Exchange Rate Connection." *CEPR, Discussion Paper series.* 7, 39

Galí, Jordi, and Tommaso Monacelli. 2016. "Understanding the Gains from Wage Flexibility: The Exchange Rate Connection." *Amercian Economic Review*, 106(12): 3829–3868. 49

Galí, Jordi, Frank Smets, and Rafael Wouters. 2012. *Unemployment in an Estimated New Keynesian Model.* National Bureau of Economic Research. 29

Galí, Jordi, J.David Lopez-Salido, and Javier Valles. 2004. "Rule-of-Thumb Consumers and the Design of Interest Rate Rules." *Journal of Money, Credit, and Banking*, 36(4): 739–763. 49

Galí, Jordi, J. David Lopez-Salido, and Javier Valles. 2007. "Understanding the Effects of Government Spending on Consumption." *Journal of the European Economic Association*, 5(1): 227–270. 49

Gelman, Andrew, John Carlin, Hal Stern, David Dunson, Aki Vehtari, and Donald Rubin. 2014. *Bayesian Data Analysis.* . Third ed., Chapman & Hall. Taylor & Francias Group. 22

Geweke, John. 1999. "Using simulation methods for Bayesian econometric models: Inference, development, and communication." *Econometric Reviews*, June. 25, 42

Goldberg, PK, and R Hellerstein. 2009. "How rigid are producer prices?" *Staff Reports, Federal Reserve Bank of New York*, November 2. 8

Gottschalk, Peter. 2005. "Downward nominal-wage flexibility: real or measurement error?" *Review of Economics and Statistics*, , (1327). 88, 95, 96, 99

Guerrieri, Luca, and Matteo Iacoviello. 2015. "OccBin: A toolkit for solving dynamic models with occasionally binding constraints easily." *Journal of Monetary Economics*, 70: 22–38. 57

Hamilton, James D. 2017. "Why You Should Never Use the Hodrick-Prescott Filter." *The review of Economis and Statistics.* 25

Hartog, Joop, Edwin Leuven, and Coen Teulings. 2002. "Wages and the bargaining regime in a corporatist setting: The Netherlands." *European Journal of Political Economy*, 18(2): 317–331. 93

Hirose, Yasuo, and Atsushi Inoue. 2015. "The zero lower bound and parameter bias in an estimated DSGE model." *Journal of Applied Econometrics.* 25

Hoeberichts, Marco, and Ad Stokman. 2006. "Price setting behaviour in the Netherlands: results of a survey." *Working Paper Series, European Central Bank*, 607. 8

Huang, Kevin, and Zheng Liu. 1999. "Staggered contracts and business cycle persistence." *Discussion Paper, Federal Reserve Bank of Minneapolis*, 127. 12

Iskrev, Nikolay. 2010. "Local identification in DSGE models." *Journal of Monetary Economics*, 57(2): 189–202. 25

Kahn, S. 1997. "Evidence of nominal wage stickiness from microdata." *The American Economic Review*, 87(5): 993–1008. 88

Karagedikli, Özer, Troy Matheson, Christie Smith, and Shaun P. Vahey. 2010. "RBCs and DSGEs: The computational approach to business cycle theory and evidence." *Journal of Economic Surveys*, 24(1): 113–136. 23

Kim, Jinill, and Sunghyun Henry Kim. 2003. "Spurious welfare reversals in international business cycle models." *Journal of International Economics*, 60(2): 471–500. 75

Kim, K., and A. R. Pagan. 1999. "The Econometric Analysis of Calibrated Macroeconomic Models." *Handbook of Applied Econometrics*, 1. 22

Kim, Sunghyun Henry. 1997. "International business cycles in a partial-risk-sharing market with capital income taxation." PhD diss. Yale University. 75

Klenow, Peter J., and O Kryvtsov. 2008. "State-dependent or time-dependent pricing: does it matter for recent US inflation?" *The Quarterly Journal of Economics*, CXXIII(August). 8, 26

Koop, Gary. 2003. *Bayesian Econometrics.* Wiley-Interscience. 25

Kurmann, André, and Erika Mcentarfer. 2017. "Downward Wage Rigidity in the United States: New Evidence from Administrative Data." *Working Paper*, 50. 88

Leith, Campbell, and Leopold von Thadden. 2008. "Monetary and fiscal policy interactions in a New Keynesian model with capital accumulation and non-Ricardian consumers." *Journal of Economic Theory*, 140(1): 279–313. 49

López-salido, J David, and Pau Rabanal. 2006. "Government Spending and Consumption-Hours Preferences." *Working paper*, , (November). 47

Lünnemann, Patrick, and Ladislav Wintr. 2009. "Wages are flexible, aren't they? evidence from monthly micro wage data." *Working Paper Series, European Central Bank*, 1074. 9, 89, 95, 96, 97, 99, 100, 103, 104

Mankiw, N. Gregory. 2000. "The Savers-Spenders Theory of Fiscal Policy." *American Economic Review Paper and Proceedings*, 90(2): 120–25. 49

Mankiw, N Gregory, and Ricardo Reis. 2002. "Sticky information versus sticky prices: a proposal to replace the New Keynesian Phillips curve." *The Quarterly Journal of Economics*, November. 12, 16, 40

Marto, Ricardo. 2014. "Assessing the Impacts of Non-Ricardian Households in an Estimated New Keynesian DSGE Model." *Swiss Society of Economics and Statistics*, 150(4): 353–398. 47

McFadden, D. 1989. "A method of simulated moments for estimation of discrete response models without numerical integration." *Econometrica: Journal of the Econometric Society*. 22

Mclaughlin, Kenneth. 1994. "Rigid wages?" *Journal of Monetary Economics*, 34: 383–414. 88

Middleditch, Paul. 2010. "A New Keynesian Model with Heterogeneous Price Setting." *ECB Working Paper Series*, 1–48. 8

Midrigan, Virgiliu. 2011. "Menu Costs, Multi-Product Firms, and Aggregate Fluctuations." *Econometrica*, 79(July): 1139–1180. 8

Motta, Giorgio, and Patrizio Tirelli. 2012. "Optimal Simple Monetary and Fiscal Rules under Limited Asset Market Participation." *Journal of Money, Credit and Banking*, 44(7): 1351–1374. 49

Nakamura, E, and J Steinsson. 2008. "Five facts about prices: A reevaluation of menu cost models." *The Quarterly Journal of Economics*, November. 8

Natvik, Gisle James. 2012. "Government Spending Shocks and Rule-of-Thumb Consumers with Steady-State Inequality." *Scandinavian Journal of Economics*, 114(4): 1414–1436. 49

Nisticò, Salvatore. 2016. "Optimal Monetary Policy and Financial Stability in a Non-Ricardian Economy." *Journal of the European Economic Association*, 14(5): 1225–1252. 49

Olivei, Giovanni, and Silvana Tenreyro. 2007. "The timing of monetary policy shocks." *The American Economic Review*. 10, 11

Pfajfar, Damjan, and Maarten de Ridder. 2017. "Policy Shocks and Wage Rigidities: Empirical Evidence from Regional Effects of National Shocks." *Cambridge-INET Working Paper Series*. 11

Rabanal, Pau. 2007. "Does inflation increase after a monetary policy tightening? Answers based on an estimated DSGE model." *Journal of Economic Dynamics and Control*, 31(3): 906–937. 29

Rabanal, Pau, and Juan F. Rubio-Ramírez. 2001. "Nominal versus real wage rigidities: a Bayesian approach." *Working Paper, Federal Reserve Bank of Atlanta*, November. 23, 26, 29

Rabanal, Pau, and Juan F. Rubio-Ramírez. 2003. "Inflation Persistence: How Much Can We Explain?" *Economic Review*, 88(2): 43–55. 35

Rabanal, Pau, and Juan F. Rubio-Ramírez. 2005. "Comparing New Keynesian models of the business cycle: A Bayesian approach." *Journal of Monetary Economics*, 52(6): 1151–1166. 26, 29

Rotemberg, JJ. 1982. "Monopolistic price adjustment and aggregate output." *The Review of Economic Studies*, 49(4): 517–531. 5

Rotemberg, Julio, and Michael Woodford. 1997. "An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy." In *NBER Macroeconomics Annual*. Vol. 12, , ed. Ben Bernanke and Rotemberg Julio, 297–361. 34

Sargent, Thomas J. 1989. "Two Models of Measurements and the Investment Accelerator." *Journal of Political Economy*, 97(2): 251–287. 23

Schmitt-Grohé, Stephanie, and Martín Uribe. 2004. "Solving dynamic general equilibrium models using a second-order approximation to the policy function." *Journal of Economic Dynamics and Control*, 28(4): 755–775. 75

Schmitt-Grohé, Stephanie, and Martín Uribe. 2005. "Optimal fiscal and monetary policy in a medium-scale macroeconomic model." *NBER Macroeconomics Annual*, 20(April): 383–425. 53

Sheedy, Kevin D. 2010. "Intrinsic inflation persistence." *Journal of Monetary Economics*, 57(8): 1049–1061. 8

Sigurdsson, Jósef, and Rannveig Sigurdardottir. 2012. "Evidence of nominal wage rigidity and wage setting from Icelandic microdata." *Working Paper, Central Bank of Iceland*, 9676(August 2012): 1–41. 9, 10

Sigurdsson, Jósef, and Rannveig Sigurdardottir. 2016. “Time-dependent or state-dependent wage-setting? Evidence from periods of macroeconomic instability.” *Journal of Monetary Economics*, 78: 50–66. 88, 89, 95, 96, 97, 99, 100, 104, 113, 115, 116

Smets, Frank, and Rafael Wouters. 2003. “An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area.” *Journal of the European Economic Association*, 1(5): 1123–1175. 29, 51, 57, 91

Smets, Frank, and Rafael Wouters. 2007. “Shocks and frictions in US business cycles: A Bayesian DSGE approach.” *American Economic Review*, 97(3): 586–606. 5, 12, 23, 26, 47, 51, 57

Spange, Morten. 2008. “International spill-over effects of labour market rigidities.” *Journal of Macroeconomics*, 30: 157–178. 50

Stahlschmidt, Stephan. 2007. “On the heterogeneity of price stickiness and its consequences for European monetary policy.” *Unpublished manuscript, Humboldt-Universitat zu Berlin*, 504055. 6

Stiglitz, Joseph. 1984. “Theories of wage rigidity.” *NBER Working Paper*, 1442. 89

Taylor, John B. 1980. “Aggregate Dynamics and Staggered Contracts.” *Journal of Political Economy*, 88(1): 1–23. 89, 91

Taylor, John B. 1999. “Staggered price and wage setting in macroeconomics.” *Handbook of Macroeconomics*, 1: 1009–1050. 40

Vermeulen, Philip, Daniel Dias, Maarten Dossche, Erwan Gautier, Ignacio Hernando, Roberto Sabbatini, and Harald Stahl. 2012. “Price Setting in the Euro Area: Some Stylized Facts from Individual Producer Price Data.” *Journal of Money, Credit and Banking*, 44(8): 1631–1650. 8

Verona, Fabio, and Maik Wolters. 2013. “Sticky information models in Dynare.” *Computational Economics*, 11. 17

Walsh, Carl. 2017. “Workers, Capitalists, Wage Flexibility and Welfare.” *Working paper*, , (July). 50, 76

Woodford, Michael. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy.* Princeton University Press. 2, 5, 11